Big Finn Hill Field Conversion

SYNTHETIC TURF STUDIES

United States
Environmental Protection
Agency

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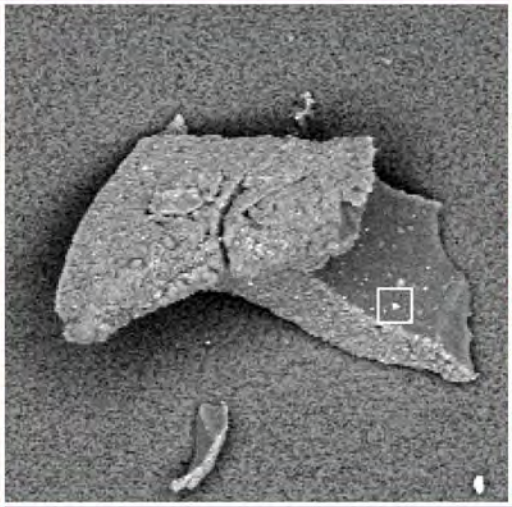

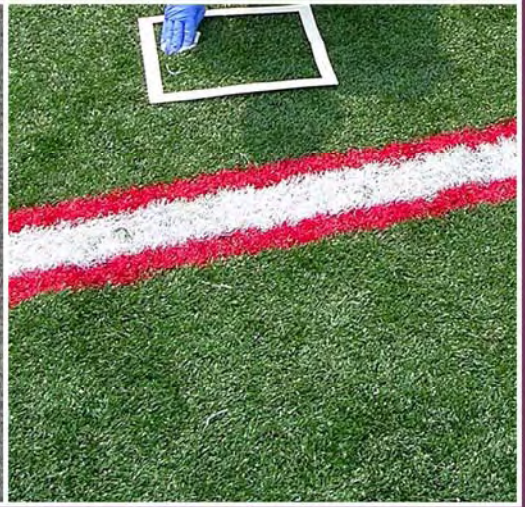

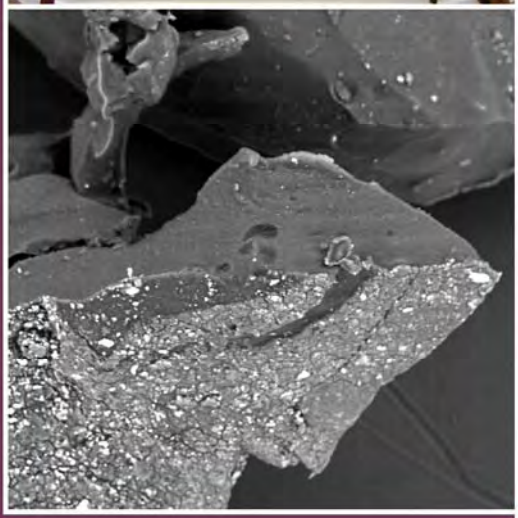

A Scoping-Level Field Monitoring Study of Synthetic Turf Fields and Playgrounds

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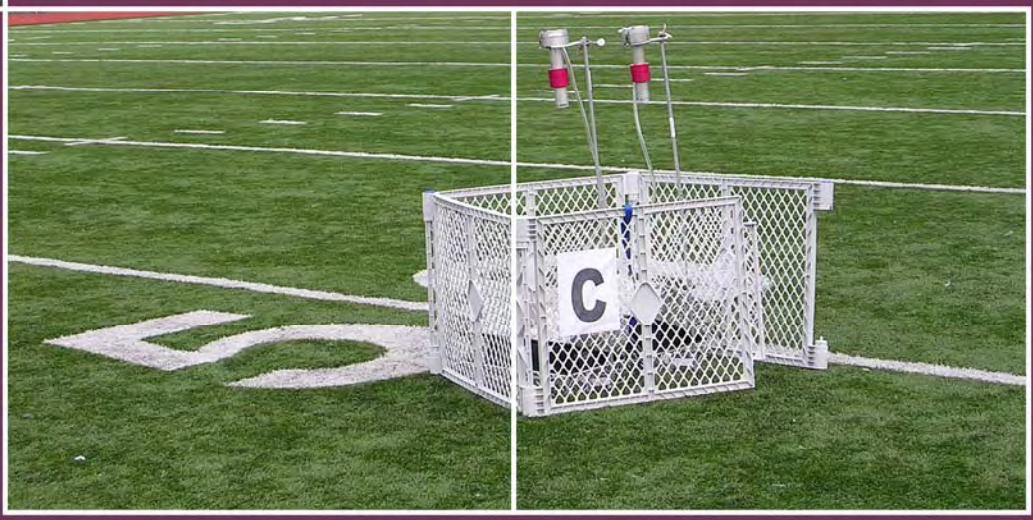

Office of
Research and Development
National Exposure
Research Laboratory

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A Scoping-Level Field Monitoring Study of Synthetic Turf Fields and Playgrounds

Prepared by the
National Exposure Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency

with contributions from the Agency's
Tire Crumb Science Workgroup

Disclaimer

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Abstract

Recycled tire material, or “tire crumb,” is used as a component in many recreational fields, including synthetic turf fields and playgrounds. The use of tire crumbs in these applications provides several benefits, including reduced sports injury. The public recently has raised concerns regarding potential human health and environmental risks associated with the presence of and potential exposures to tire crumb constituents in recreational fields, especially with regard to children’s exposures.

In early 2008, U.S. Environment Protection Agency (EPA) Region 8 requested that the Agency consider this issue. A cross-EPA workgroup inventoried and considered the limited available scientific information: some laboratory studies of tire material content, off-gassing, and leaching characteristics and a few European studies describing the extent and availability of tire crumb constituents for potential human exposure. The workgroup recommended that research be conducted to generate additional field monitoring data for potential U.S. environmental conditions and potential exposures.

A limited-scale study was conducted during the 2008 summer and fall seasons to

(1) gain experience conducting multiroute field monitoring of recreational surfaces that contain tire crumb by evaluating readily available methods for measuring environmental concentrations of tire crumb constituents; and
(2) generate limited field monitoring data that will be used by EPA to help the Agency determine possible next steps to address questions from the public regarding the safety of tire crumb infill in recreational fields.

The field sites were selected based on availability and proximity to facilities of EPA’s National Exposure Research Laboratory; thus, the results reported here may not be representative of environmental concentrations found at other sites. Because validated methods for sampling synthetic turf fields or playgrounds did not exist, methods used for other microenvironmental sampling were used. The full study protocol was implemented at two synthetic turf fields and one playground. At each field and the playground, air sampling was conducted to collect integrated particulate matter (PM_{10}) and grab volatile organic chemical (VOC) samples at two to three locations on each turf field and playground and also at an upwind background location. The air samples were collected at a height of 1 m in close proximity to, but without interfering with, planned recreational activities. The VOC samples were collected around 2:00 p.m. Wipe samples were collected at the three turf field sampling locations, along with readily available tire crumb infill and turf blade samples. Tire crumb material was collected from the playground. The full protocol was implemented at one of the synthetic turf fields on a second consecutive day providing repeat sampling data. Selected samples were collected at a few additional synthetic turf fields and one playground.

Standard laboratory analysis methods were employed to analyze the environmental samples for the targeted analytes. The PM_{10} samples were analyzed for PM mass, metals, and particle morphology. The VOC samples were analyzed for 56 volatile organic analytes. The wipe and material samples were analyzed for total extractable concentrations of several metals and bioaccessible lead.

Key findings are summarized below.

(1) The study protocol and many of the methods were found to be reliable and could be implemented in the field. Several limitations are noted below.
    a. Collecting integrated air samples provided a high burden in terms of time and equipment.
    b. Semivolatile organic compounds were not measured.
    c. At any single site, there can be substantial variability in the materials used and the concentrations of contaminants measured. More work is needed to determine where to collect samples and how many samples to collect to fully characterize a given site.

d. It was difficult to obtain access and permission to sample at playgrounds and synthetic turf fields. More work is needed to increase public and private owner participation if additional monitoring studies are conducted.

(2) Methods used to measure air concentrations of PM_{10} and metals were found to be reliable.
   a. Concentrations of PM_{10} and metals (including lead) measured in air above the turf fields were similar to background concentrations.
   b. Concentrations of PM_{10} and metals at the playground site with high play activity were higher than background levels.
   c. All PM_{10} air concentrations were well below the National Ambient Air Quality Standards (NAAQS) for PM_{10} (150 $\mu g/m^3$). All air concentrations for lead were well below the NAAQS for lead (150 ng/m^3).

(3) Methods used to measure VOCs in air were found to be reliable.
   a. All VOCs were measured at extremely low concentrations that are typical of ambient air concentrations.
   b. One VOC associated with tire crumb materials (methyl isobutyl ketone) was detected in the samples collected on one synthetic turf field but was not detected in the corresponding background sample.

(4) Methods used to measure extractable metals from turf field blades, tire crumb materials, and turf field wipe samples were found to be reliable. However, the aggressive acid extraction procedure likely will overestimate the concentration of metals that are readily available for human uptake. Since understanding uptake is a key component in understanding risk, methods to determine bioavailable metal concentrations still are needed.
   a. Total extractable metal concentrations from the infill, turf blade samples and tire crumb material were variable in the samples collected at a given site and between sites.
   b. The average extractable lead concentrations for turf blade, tire crumb infill, and tire crumb rubber were low. Although there are no standards for lead in recycled tire material or synthetic turf, average concentrations were well below the EPA standard for lead in soil (400 ppm).
   c. Likewise the average extractable lead concentrations for turf field wipe samples were low. Although there are no directly comparable standards, average concentrations were well below the EPA standard for lead in residential floor dust (40 $\mu g/ft^2$).

(5) On average, concentrations of components monitored in this study were below levels of concern; however, given the very limited nature of this study (i.e., limited number of components monitored, samples sites, and samples taken at each site) and the wide diversity of tire crumb material, it is not possible to reach any more comprehensive conclusions without the consideration of additional data.

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Executive Summary

Background

Recycled tire material, or “tire crumb”, is used in many applications, including as a component in synthetic turf fields and playground installations. The use of tire crumbs in these applications provides several benefits, including but not limited to reduced impact injuries; reduced or eliminated use of water, fertilizer, and pesticides needed to maintain grass fields; reduced need for disposal of used tires in landfills; and increased availability of fields for recreation. The public recently has raised concerns regarding potential human health and environmental risks associated with the presence of and potential exposures to tire crumb constituents in recreational fields, especially with regard to children’s exposures.

In early 2008, U.S. Environmental Protection Agency (EPA) Region 8 requested that the Agency consider this issue, and a cross-EPA workgroup was formed. The workgroup inventoried and considered the limited available scientific information: laboratory studies of tire material content, off-gassing, and leaching characteristics. Also, a few European studies reported data describing the extent and availability of tire crumb constituents for potential human exposure through various routes and pathways (inhalation, ingestion, and dermal contact).

In the late spring of 2008, a smaller EPA Tire Crumb Science Workgroup (science workgroup) subsequently was formed and charged to consider the quality of the current science and make recommendations regarding the need for future research. Because minimal environmental or exposure data for U.S. populations were available, a limited scoping study was proposed and designed to evaluate a protocol and methods for generating consistently collected U.S. environmental data for select tire crumb constituents.

This report provides the EPA scoping study results. The EPA scoping study results, along with results from other studies conducted by Federal, State, and local organizations, such as the Consumer Product Safety Commission (CPSC); the Agency for Toxic Substances and Disease Registry; States including New Jersey, Connecticut, California, and New York; and New York City, will be considered by EPA to identify possible next steps to address questions from the public regarding the safety of tire crumb infill in ball fields and playgrounds.

Scoping Study Objectives

The EPA science workgroup proposed a limited scoping-level study during 2008 that included the following elements.

- Evaluate, through real-world measurements, the application of readily available sampling and analysis methods for characterizing environmental concentrations of selected tire crumb contaminants in and around playgrounds and synthetic turf fields.
- Evaluate the overall study protocol (monitoring, analytical, and quality control [QC] procedures) for generating the quantity and quality of environmental measurement data needed to characterize the contribution of the tire crumb constituents to environmental concentrations.
- Collect a limited environmental dataset to help understand and assess methods for characterizing potential route- and pathway-specific exposures (inhalation, ingestion, and dermal) based on selected sentinel species.
- Generate a limited set of consistently collected field measurement data from a very few playgrounds and synthetic turf fields that, along with other study data, may be used to develop insights regarding the importance of the various exposure routes and pathways and to inform decisions regarding possible next steps to address questions from the public regarding the safety of tire crumb infill in ball fields and playgrounds.

Study Approach

The proposed final study design included the collection and analysis of selected air, wipe, and material samples at one playground and one synthetic turf field site in the EPA regions where the four National Exposure Research Laboratory (NERL) facilities are located. This design (a total of eight sites) was based on the availability of NERL technical support. During a single daytime period at each site, air samples were to be collected at up to three “on field” or “on playground” sampling locations within the site boundaries in areas as close to anticipated human activity as possible without interfering with routine activities. Air samples also were to be collected at site background upwind sampling locations to characterize local ambient background levels. A comparison of “on playground” or “on field” data with the background data would be used to characterize the environmental availability of tire crumb constituents. Surface wipe samples were to be collected at the “on field” air sampling locations, but not at the background sampling location. Tire crumb and synthetic turf blade samples were to be collected at multiple sampling locations, but these were not always the same locations as the air sampling locations. The following samples were planned for collection and analysis.

- Grab air samples during the hottest daytime period (~2:00 p.m.) to assess organic vapor concentrations (56 volatile organic compounds [VOCs])
- Integrated air particulate matter (PM_{10}) samples to assess particle mass concentrations and concentrations of selected metals (including lead [Pb], chromium [Cr], zinc [Zn], and others)
- Integrated air PM_{10} samples to characterize ambient particles based on morphology (sizes and structure) using scanning electron microscopy (SEM) and, if possible, to estimate the relative contribution of tire crumb particles to the overall particle mass
- Wet surface wipe samples to assess environmental concentrations of metals (e.g., Pb, Cr, Zn, and others) associated with turf field materials (tire crumb rubber and turf blades)
- Turf field tire crumb infill granules, turf blades, and playground tire crumb material to assess concentrations of metals (e.g., Pb, Cr, Zn, and others) associated with these materials
- Field and laboratory QC samples to document the quality of the study data. Duplicate samples for each measure described above were collected where appropriate. Routine field and laboratory QC samples (e.g., blanks, spikes) also were analyzed.

Study Limitations

This limited scoping-level study was designed to evaluate the methods for generating quality environmental data for selected tire crumb constituents and for understanding potential exposure routes and pathways. The study was planned based on readily available resources (personnel, equipment, media, etc.) and in consideration of the workgroup’s desired study time period (the summer and early fall of 2008). This time period was recommended, as the projected high ambient temperatures should result in conditions promoting the greatest potential for the environmental release of tire-related constituents.

This study and the resulting data have many limitations. The study was not designed to provide representative U.S. environmental measurement data for all tire crumb constituents or applications. Nor was the study designed to inform conclusions regarding differences in U.S. environmental concentrations or potential exposures to turf field and playground tire crumb constituents based on geographical location, type, manufacturing materials, age, use, or conditions. The study also was not designed to compare potential exposures to turf field and playground tire crumb constituents with those at natural turf fields or playgrounds constructed with other types of surfaces. The study collected limited environmental data to help understand and assess methods for characterizing potential route- and pathway-specific exposures (inhalation, ingestion, and dermal) based on selected sentinel species. No personal exposure data or related information were collected. Validated sampling and analysis methods for characterizing recreational fields were not available, so existing methods used in similar studies

were applied. The study did not evaluate methods for all the reported tire crumb constituents. Semivolatile organic compounds (SVOCs [e.g., benzothiazole, aniline, polycyclic aromatic hydrocarbons (PAHs)]) reported in some studies were not sampled or analyzed because of resource limitations.

Sample Collection Results

Sampling Sites

The full study protocol was implemented at only two synthetic turf field sites (F1 and F4) and one playground site (P1), fewer than the planned four turf field and four playground sites. Difficulties in identifying and arranging site access, logistical limitations, and personnel requirements to operate the extensive array of equipment and sites were the key factors impacting the number of sites monitored.

Unplanned sampling also occurred and is reported herein. The full protocol was conducted at F1 on a second consecutive day providing repeat measures. A reduced set of samples (without integrated air particle monitoring) was completed at a third synthetic turf field site consisting of two collocated fields (F2 and F3). Some samples were collected for two additional turf fields (F5 and F6) collocated with F4. Two F4 “on field” sampling locations were very near a busy commuter road and parking deck.

When a site consisted of multiple fields, one field was designated as the primary location for implementing the protocol. In total, samples were collected for six different synthetic turf fields.

Gaining access to playgrounds was very difficult and became even more difficult with increased media attention. The full sampling protocol was completed at only one playground (P1) and at only two “on playground” sampling locations because of space limitations. Tire crumb material molded to mimic wood bark was obtained from a second playground site (P2).

Sample Collection and Analysis Methods

Air VOCs. Grab air VOC samples (6-L Summa-polished stainless steel canisters) were collected at each sampling location at a 1-m inlet height during the hottest time of day (~2:00 p.m.). The standard EPA Method TO-15 gas chromatography/mass spectrometry (GC/MS) analytical method provided ambient-level concentration measurements for 56 VOC analytes.

Air Particulate Matter. Two integrated air PM_{10} samples (one for particle mass and metals analysis and another for scanning electron microscopy [SEM] analysis) were collected at each sampling location at a 1-m inlet height over collection periods ranging from 5.8 to 7.8 h. This resulted in individual sample air volumes ranging from approximately 7.0 to 9.2 m^3 (3.5 to 5.0 m^3 for SEM samples). PM_{10} mass was determined gravimetrically; metal concentrations by X-ray fluorescence; and assessment of particle size and morphology and attempts to identify the tire crumb component contribution by SEM.

Synthetic Turf Field Surface Wipes. No known validated methods exist for characterizing environmental concentrations of metals on synthetic turf surfaces comprised of both turf blades and tire crumb rubber. A standard wet-wipe method (American Society for Testing and Materials [ASTM] E1728-03) used routinely to measure residential surface dust Pb levels was used for this study. Advantages of this method were the availability of standard wipe material and the existing, well-characterized, sampling and analytical methodologies. Samples were collected at each “on field” turf field sampling location. Wipe samples were not collected at the “on playground” or background sampling locations. Each surface wipe, tire crumb, and turf blade sample (described below) was extracted first using the EPA In Vitro Relative Bioaccessibility Assessment Method 9200.1-86. (Note: In vitro methods measure the bioaccessibility [e.g., solubility] of metals during a simulated gastric extraction process to assess the percentage of a metal in a material that may become available for absorption in the gastro-

intestinal [GI] tract.) The same material from each sample then was extracted using EPA Method 3050B. A total extractable concentration of Pb, Cr, Zn, arsenic (As), aluminum (Al), barium (Ba), cadmium (Cd), copper (Cu), iron (Fe), manganese (Mn), and nickel (Ni) was determined by an analysis of the combined bioaccessibility and Method 3050B extracts. Extracts were analyzed by inductively coupled plasma (ICP)/MS using EPA Method 6020A. The percent bioaccessible Pb was calculated from the relative amount in the bioaccessible extract as compared with the total extractable amount.

Synthetic Turf Field Tire Crumb Infill. Tire rubber infill was collected randomly at the synthetic turf fields. In this study, it was decided to collect infill material that was readily available at the surface rather than dislodging material trapped deep within the turf blades. This decision was based partly on avoiding potential damage to field components but primarily because the material on the surface was more available for potential human contact. Infill material was not available uniformly across the field surface.

Synthetic Turf Field Blades. Blades were randomly collected at the synthetic turf fields. Collecting blades of each color present at the field was attempted. Turf blade collection relied on the availability of loose blades found on the field surface in lieu of a destructive (i.e., cutting) method. Collection and analysis decisions were complicated by the limited availability of loose blades and a later determination that a minimum of 0.7 g of material was required for analysis.

Playground Tire Crumb Rubber. Tire crumb samples were obtained from two playground sites. It was not clear how many pieces needed to be collected nor at what depth (surface/subsurface) for site characterization, as the crumb shifts with mechanical action. A further challenge is that relatively small amounts (1 g or less) are required for analysis; large amounts may overwhelm the digestion and analytical systems. Intact tire crumb rubber pieces were larger than 1 g. A decision was made not to cut samples, as this would expose unweathered surfaces and possibly impact the bioaccessible Pb estimate.

Conclusions

The key study findings are summarized below. The narrative and appendixes that follow this Executive Summary provide additional details regarding the study, along with all of the measurement and laboratory data. This descriptive report focuses on the study design and methodologies; assessing the methodology for characterizing environmental concentrations of tire crumb constituents in future studies; describing the quality of the scoping study data; and providing recommendations for consideration in the design of any future research, if needed.

In general, the study protocol is expected to reliably yield data for assessing environmental concentrations of selected tire crumb constituents and understanding potential exposure routes and pathways. However, when considering future study designs and implementation, the research needs to carefully consider issues associated with identifying and gaining site access, the cost benefit of obtaining the data versus the resource burden, and the implementation of other methods for generating data to address specific research hypotheses. Future studies will need a carefully developed and implemented communications plan to promote the value of the research and gain access to the required facilities.

(1) The study protocol and many of the methods were found to be reliable and could be implemented in the field. Several limitations are noted as follows.
- Collecting integrated air samples provided a high burden in terms of time and equipment.
- SVOCs were not measured.
- At any single site, there can be substantial variability in the materials used and the concentrations of contaminants measured. More work is needed to determine where to collect samples and how many samples to collect to fully characterize a given site.

- It was difficult to obtain access and permission to sample at playgrounds and recreational fields. More work is needed to increase public and private owner participation if these studies are to be implemented.

(2) Methods used to measure air concentrations of PM_{10} and metals were found to be reliable.

- Concentrations of PM_{10} and metals (including Pb) measured in air above the turf fields were similar to background concentrations.
- Concentrations of PM_{10} and metals at the playground site with high play activity were higher than background levels.
- All PM_{10} air concentrations were well below the National Ambient Air Quality Standards (NAAQS) for PM_{10} (150 $\mu g/m^3$). All air concentrations for Pb were well below the NAAQS for Pb (150 ng/m^3).

(3) Methods used to measure VOCs in air were found to be reliable.

- All VOCs were measured at extremely low concentrations that are typical of ambient air concentrations.
- One VOC associated with tire crumb materials (methyl isobutyl ketone) was detected in the samples collected on one synthetic turf field but was not detected in the corresponding background sample.

(4) Methods used to measure extractable metals from turf field blades, tire crumb materials, and turf field wipe samples were found to be reliable. However, the aggressive acid extraction procedure likely will overestimate the concentration of metals that are readily available for human uptake. Because understanding uptake is a key component in understanding risk, methods to determine bioavailable metal concentrations are still needed.

- Total extractable metal concentrations from the infill, turf blade samples, and tire crumb material were variable both between sites and at the same sites.
- The average extractable lead concentrations for turf blade, tire crumb infill, and tire crumb rubber were low. Although there are no standards for Pb in recycled tire material or synthetic turf, average concentrations were well below the EPA standard for lead in soil (400 ppm).
- Likewise the average extractable Pb concentrations for turf field wipe samples were low. Although there are no directly comparable standards, average concentrations were well below the EPA standard for lead in residential floor dust (40 $\mu g/ft^2$).

(5) On average, concentrations of components monitored in this study were below levels of concern; however, given the very limited nature of this study (i.e., limited number of components monitored, samples sites, and samples taken at each site) and the wide diversity of tire crumb material, it is not possible to reach any more comprehensive conclusions without the consideration of additional data.

1. Introduction

1.1 Background

Tire crumb or crumb rubber is produced from scrap tires or from the tire retreading process. During the recycling process, steel and usually fiber are removed, and the remaining rubber material is processed either by mechanical means or through freeze cracking into “chips” or into various sizes of rubber mesh with a granular consistency. Tire crumb is used in several commercial applications, including road construction, sidewalks, automobile parts, and in a number of athletic and recreational applications. Recreational uses include ground cover (chips) under playground equipment, landscaping mulch (chips), running track material (granular or molded), and filler material used with many synthetic turf sports and playing fields (granular).

The use of tire crumb materials for playground and turf fields provides numerous benefits. First, it cushions falls, reducing sports injuries when compared with other playground or athletic surfaces. Second, synthetic turf is a low-maintenance alternative to natural grass, as there is no or reduced need for water, fertilizers, or pesticides. Because turf fields are installed with below-ground drainage systems, there is reduced waiting time after storms, which promotes their use. Third, reusing expended tires reduces their potential as disease vectors (e.g., water hosting mosquitoes) and reduces the burden on landfills.

There have been increased reports in the media of parents becoming alarmed when their children returned home with tire crumb particles or fragments adhering to their socks and clothing picked up while playing on tire-crumb-surfaced playgrounds and turf fields. The U.S. Environmental Protection Agency (EPA) Region 8 asked several EPA program offices to help understand the extent of crumb rubber recreational uses, fill critical data gaps, and assess the available data to determine if there was any unreasonable exposure or risk, particularly to children. In response to this request, an Agency-wide workgroup was formed to assess the existing information and determine whether the Agency needed to collect additional information. The workgroup included representatives from the various program, policy, scientific, and communications staff, including the Office of Children’s Health Protection and Environmental Education (co-lead), the Office of Pollution Prevention and Toxic Substances, the Office of Solid Waste and Emergency Response, the Office of Research and Development (ORD; co-lead), and several EPA regional offices. The workgroup requested that a smaller science workgroup familiar with planning and conducting environmental field studies be formed to consider the quality of the current science and make recommendations regarding the need for future research, if any is needed.

This scoping study was proposed, designed, and recommended by the science workgroup as a means for evaluating readily available methods and to generate consistently collected U.S. data that could be used to help inform decisions regarding possible next steps to address questions from the public regarding the safety of tire crumb infill used in ball fields and playgrounds. This study was not intended to address the very large number of variables that might impact environmental concentrations or potential exposures (e.g., manufacturers, materials, installation practices, spatial/temporal differences, age, use). The limited study data were intended to complement data collected or planned for collection by other State and Federal agencies. Although this study included collection and analysis of environmental samples that may be associated with several synthetic turf components, the focus of EPA’s work is developing and evaluating methods for characterizing tire crumb constituents. Analysis of the other components was included to better understand the relative portion of any observed tire crumb constituent environmental levels measured in the various samples. This study may complement research performed by the Consumer Product Safety Commission (CPSC); the States of California, New Jersey, New York, and Connecticut; and New York City regarding synthetic turf, but is distinct from the other studies in that the focus is on the tire crumb material.

Prior to preparing for a scoping study, a search of the scientific literature revealed limited environmental or exposure measurement data associated with the use of tire crumb rubber for U.S. recreational fields. Only a few peer reviewed laboratory or environmental studies were reported, with many of these studies conducted in Europe.

Although the results were limited, the search identified a number of compounds and metals that *may* be found in tires, although not all of these compounds and metals are contained in every tire nor are they contained in the same concentration in any tire at any given time. These compounds and metals include those that follow.

Acetone
Aniline
Benzene
Benzothiazole
Chloroethane
Halogenated flame retardants
Isoprene
Methyl ethyl ketone
Methyl isobutyl ketone
Naphthalene
Phenol
Polycyclic aromatic hydrocarbons
Styrene-butadiene
Toluene
Trichloroethylene
Arsenic
Barium
Cadmium
Chromium
Cobalt
Copper
Lead
Manganese
Mercury
Nickel
Sulfur
Zinc
Pigments
Nylon
Polyester
Rayon
Latex

1.2 Exposure Science Questions

A series of general science questions was considered before the study protocol was developed; they include the following ones.

- Can existing collection and analysis approaches and methods be used to assess environmental concentrations of tire crumb rubber constituents at synthetic turf fields and playgrounds?
- How well do such methods perform under real-world conditions?
- Do the methods produce data of sufficient quality to characterize potential exposure routes and pathways?
- Do the methods produce data of sufficient quality to characterize the contribution of constituents to various sources?
- Are the data and information produced through this research, when included with data from other studies, useful for developing hypotheses and informing the design of future research, if needed?
- What new methods are needed to fully characterize tire crumb environmental concentrations and to understand potential exposure routes and pathways?

1.3 Project Objectives

The science workgroup planned a very limited scoping-level field measurement study during the 2008 summer/fall season to

- evaluate, through real-world measurements, the application of readily available sampling and analysis methods for characterizing environmental concentrations of selected tire crumb contaminants in and around playgrounds and synthetic turf fields;
- evaluate the overall study protocol (monitoring, analytical, and QC procedures) for generating the quantity and quality of environmental measurement data needed to characterize the contribution of the tire crumb constituents to environmental concentrations;
- generate a limited set of consistently collected field measurement data from a few playgrounds and synthetic turf fields that, along with other study data, may be used to

develop insights regarding the importance of the various exposure routes and pathways and inform the decision regarding future research, if any is needed; and
- understand the factors influencing the development and implementation of future study protocols.

1.4 Study Limitations

This study was designed as a limited scoping-level methods evaluation study. It was planned based on readily available resources (personnel, equipment, media, etc.) and in consideration of the workgroup's desired study time period, the 2008 summer and early fall months when high ambient temperatures should result in conditions promoting the greatest potential for release of tire-related constituents. The study collected limited environmental data to help understand and assess methods for characterizing potential route and pathway-specific exposures (inhalation, ingestion, and dermal) based on selected sentinel species. This study and the resulting data have many limitations, which are described below.

- The study was not designed to provide representative U.S. environmental measurement data for all tire crumb constituents or applications, nor to make conclusions regarding differences in environmental concentrations or potential U.S. exposures to field and playground tire crumb constituents based on geographical location, type of recreational field, manufacturing materials, age, use, or conditions. Resource constraints prohibited the survey, coordination, and random selection of U.S. playgrounds and turf fields and the use of the study data in supporting statistical analysis or making statistical inferences. The study results can be used only to describe the playgrounds and turf fields monitored.
- The number of samples collected at each site was relatively small and will not necessarily support the spatial characterization of the species concentrations across the monitored area.
- Sampling was planned to be conducted only on one day. Therefore, temporal characterization of the targeted environmental contaminants will not be supported.
- No personal exposure data or related information were collected.
- No scripted activities were planned or conducted. The study results were dependent on normal activity levels by the individuals using the playground or turf field. However, the limited data collected in this study likely will not be useful in characterizing differences associated with these factors.
- The study did not evaluate methods for all the reported tire crumb constituents. Sampling and analysis of semivolatile organic compounds (SVOCs; e.g., benzothiazole, aniline, polycyclic aromatic hydrocarbons [PAHs]), reported in many studies, were not performed because of resource limitations.
- Validated sampling approaches and analysis methods were not available for real-world playground and synthetic turf field conditions. Currently accepted methods for measurement and analysis of the targeted species in indoor and outdoor microenvironments and in soils were used, with modifications required in some cases.
- QC/QA activities were implemented to document the quality of the sampling and analysis measurements; however, suitable QA/QC materials and standards were not available for some of the types of samples.

2. Conclusions and Recommendations

The following narrative provides key highlights regarding the approach and methods that were applied and assessed in this scoping study. The study results are being provided to the workgroup for assessment and interpretation.

2.1 Implementation of the Study Protocol

- A small scoping-level study protocol was fully implemented at two synthetic turf fields and one playground. The protocol was successfully implemented at one of these fields on a second day, providing a set of unplanned consecutive day data. Additional data were collected from four turf fields and for tire crumb from a second playground.
- The study's success reflects the excellent collaborations and contributions of scientists and staff across many program offices, regions, States, and ORD.
- The protocol, and a majority of the corresponding methods employed in this study, generated quantitative data that can be used to characterize the contribution of tire crumb constituents to the environmental concentrations measured at the synthetic turf field, playground, and background sampling locations.
- Although none of the methods have been validated for this specific application, most methods were able to provide measurement data of known quality and at concentrations adequate for assessing potential tire crumb constituents.
- Air particle collection required considerable time, equipment, and expertise.
- Other collection procedures (air volatile organic compounds [VOCs]), wipe, and material collection) required much less time, equipment, and expertise.
- In general, the study protocol can be implemented and will yield data for assessing environmental concentrations and potential exposures for tire crumb constituents for various routes and pathways. However, when considering the design and implementation of future studies, the research needs to carefully consider
  - issues associated with identifying and gaining site access,
  - the value of the data being generated versus the resource burden, and
  - the implementation of other methods for generating data to address specific research hypotheses.
- Any future study will need a corresponding carefully developed and implemented communications plan to help promote the value of the research and gain access to the required facilities.

2.2 Air Sampling and Analysis

- The air sample collection and analysis methods provided data suitable (both quality and concentration levels) for assessing environmental levels of particles, metals, and VOCs in air.
- Air particulate matter sampling employing relatively large (carry-on-size suitcase), battery-operated pumps and size selective inlets yielded sufficient particle mass for measuring selected metals at commonly reported ambient air levels. This sampling approach required significant resources (equipment and experienced field staff) and long setup and sampling durations (8 to 10 h).
- Collecting air VOCs via grab sampling during the hottest daytime period (conditions when the greatest emissions from tire crumb material were anticipated) was simple and required little time (~1 h).
- The air VOCs methods generated concentration data for many compounds. Slightly elevated MIBK levels were found at one turf field. The reproducibility in the data approximates what previously has been reported in other field measurement studies. The use of an integrated

sampling pump method likely would increase the number of species with reportable data but would not necessarily generate substantially different data for characterizing tire crumb source contributions, environmental concentrations, or potential exposures.

- The air particulate matter (PM) mass and metals methods yielded reproducible results, with the turf field concentrations approximating the background levels. Concentrations on one playground site were somewhat higher than the background concentration.
- Tire crumb related fibers were not observed in the air samples analyzed by scanning electron microscopy (SEM). The SEM data were not sufficient for source apportionment or attribution of the data to any tire crumb constituent because of the variability of compositional or morphological characteristics of particles associated with the tire crumb material collected in this study.

2.3 Surface Wipe, Tire Crumb, and Turf Blade Sampling and Analysis

- No evaluated method was available for assessing dermal and indirect ingestion from tire crumb constituents in turf field or playground surfaces. A standard surface wet wipe sample collection method for residential lead (Pb) measurement was used at the synthetic turf fields. This method performed reasonably well for assessing extractable metals and required modest skills and time (~1 h).
- Collection of tire crumb infill and turf blade material at synthetic turf fields and tire crumb at playgrounds was straightforward, requiring minimal skills and resources (~1 h). Convenience samples were collected in this study based on the materials being readily available on the surface. There is evidence that the material is not homogeneous with regard to some constituents (Pb for example). Future site characterization studies should be considered to evaluate the issue of sample heterogeneity and the impact on data interpretation.
- Wipe, tire crumb, and turf blade samples were extracted using EPA Method 9200.1-86 for in vitro Pb bioaccessibility and EPA Method 3050B for total extractable Pb (and other metals). Both extraction techniques were combined with EPA inductively coupled plasma (ICP)/MS Method 6020A. These methods require extensive skill and resources. Multiple analyses of sample extracts with varying dilutions were required to capture the range of elements and concentrations within appropriate calibration parameters.
- The in vitro Pb bioaccessibility method was judged not appropriate for the surface wipe samples. Because the in vitro method has been validated only for soil samples, additional validation studies would be required to fully demonstrate the relevance of the method for tire crumb and turf blade materials.
- Although the methods appeared to perform reasonably well, a number of sample handling, size, and heterogeneity issues were discovered that may affect method performance and data interpretation.
- There is a lack of appropriate QC/QA materials and spiking methods. QA/QC materials and procedures need further development for the methods as applied to these materials.
- The wipe, tire crumb, and turf blade data identified a potentially significant variability in source contribution based on turf field blade color and type, along with the tire crumb fraction being analyzed. Additional research is needed to understand the factors influencing the reported variability before future studies are designed and conducted. Understanding the variability is important in developing improved approaches for site characterization.

2.4 Conclusions with Regard to the Exposure Science Questions

- Can existing collection and analysis approaches and methods be used to assess environmental concentrations of tire crumb rubber constituents at synthetic turf fields and playgrounds? Yes, existing air sampling and analysis methods can be used. Existing methods

for analysis of metals in synthetic turf field and playground components can be successfully applied, but may require additional validation assessments.

- How well do such methods perform under real-world conditions? The air sampling and analysis methods evaluated performed well. Methods for analysis of metals in synthetic turf field and playground components showed good precision, but the assessment of recovery for some metals was difficult because of the nonhomogeneity of the bulk materials.
- Do the methods produce data of sufficient quality to characterize potential exposure routes and pathways? In most cases, the methods appeared to produce data of sufficient quality with regard to sensitivity, precision, and accuracy. Additional validation efforts may be needed to interpret measurement results, particularly with regard to bioaccessibility of metals in synthetic turf field and playground components.
- Do the methods produce data of sufficient quality to characterize the contribution of constituents to various sources? Some of the methods generated data of sufficient quantity and quality. Research is needed to better understand relative source contributions, in particular for the wipe and air particle samples.
- Are the data and information produced useful, when included with data from other studies, for developing hypotheses and informing the design of future research, if needed? The assessment of approaches and methods tested in this scoping study, in combination with research recently completed and ongoing by other organizations, will be very useful for developing hypotheses and informing the design of future research, if needed.
- What new methods are needed to fully characterize tire crumb environmental concentrations and to understanding potential exposure routes and pathways? Testing and application of personal sampling methods would provide a more complete understanding of how environmental concentrations translate into potential exposures. Methods for collection and analysis of SVOCs were not tested in this scoping study but would be needed for a full characterization.

3. Scoping Study Approach

3.1 Scoping Study Goals

The primary goal of this scoping study was to evaluate readily available methods and approaches for characterizing environmentally available concentrations of selected contaminants at synthetic turf fields and playgrounds that include tire crumb material. There are currently no known validated sampling and analysis methods for these types of installations and materials. Integrated and/or grab air, wipe, and material sample collection and analysis methods (Table 1) were selected based on professional evaluation. Where available, standard methods used routinely to characterize the targeted environmental contaminants in other microenvironments were selected. However, because of time and resource constraints, none of these methods were evaluated for the intended study application. A list of the sample collection and analysis methods used or developed for this study is provided in Appendix A. The detailed methods were included in the approved study QA project plan.

A number of constraints influenced the decisions on proposed methodologies. These included limited resources (e.g., time, people); an anticipated lack of readily available electrical power at the sites; uncertainty in sample collection times because of site availability or activity issues; the need for equipment that can be shipped to multiple sites across the country; and the need for rugged, simple methods that could be implemented consistently by minimally trained technical staff at several sites.

3.2 Organizations

The scoping study approach was developed based on the cross-Agency collaborative effort outlined below.

- National Exposure Research Laboratory (NERL): Prepare and ship sample collection equipment and media (less VOCs [see below]). Provide technical support for measurements. Analyze air filter media for mass, metals, and morphology. Analyze tire crumb material, turf blade material, and surface wipes for metals.
- EPA Regions 4, 5, and 9: Identify, assess, and coordinate access to the study sites. Communicate study to the public.
- EPA Region 1: Prepare VOC sampling media (canisters) and conduct TO-15 analyses.
- Workgroup: Assessment and interpretation of the study data provided in this report in context with other research data and Agency compliance guidelines following receipt of this report.

3.3 Selection of Target Analytes

Target analytes in this study were selected based on a combination of three factors: (1) chemicals that have been associated with tire material (see Section 1.1); (2) chemicals that have been reported in other measurement studies at synthetic turf fields or playgrounds or are of interest for these types of facilities; and (3) chemicals that could be analyzed using the methods and resources that were readily available for this study. Methyl isobutyl ketone (MIBK) was selected as a potential marker for emissions of volatile tire components into the air. PM_{10} was selected because it may occur from physical degradation of tire crumb material and its potential for activity-related suspension into the air. PM_{10} particles are of interest because they may be inhaled and also swallowed following trapping by mucus membranes. The metals Pb and chromium (Cr) were of interest both because of their potential presence in tire material, and also because they have been shown to be associated with pigments used in some types of synthetic turf blades.

The metal zinc (Zn) was of interest as a potential marker for tire crumb material. Other metals were of secondary interest because of their potential association with tire material or because they can provide additional particle source information. In some cases, additional VOC or metal

Table 1. Summary of Sample Collection and Analysis Methods

Sample Type	Sites	Sampling Method	Analytical Method	Target Analytes
Air Particulate Matter (PM_{10}—particles with aerodynamic size <10 µm)	Synthetic turf fields Playgrounds	ORD/NERL Research Protocol SKC pump, gel-cell battery, Harvard 10-µm impactor, 37-mm Teflon filter, 20-L/min flow rate 1-m sampling height, three sites on/near playground/field, one site for background	ORD/NERL Research Protocol Gravimetric analysis	PM_{10} mass
Air Metals in PM_{10}	Synthetic turf fields Playgrounds	Same sample as collected for PM_{10} mass.	ORD/NERL Research Protocol XRF (X-ray fluorescence)	Primary: Pb, Cr, Zn Secondary: Ca, Cl, Cu, Fe, K, Mn, S, Si, Ti
Air Particles/ Fibers for Scanning Electron Microscopy (SEM)	Synthetic turf fields Playgrounds	ORD/NERL Research Protocol SKC pump, gel-cell battery, Harvard 10-µm impactor, polycarbonate filter, 10 L/min Same sites and height as PM_{10}	ORD/NERL Research Protocol SEM (scanning electron microscopy)	Particle morphology Particle size distribution Attempt to characterize tire crumb composition signature
Air Volatile Organic Compounds (VOCs)	Synthetic turf fields Playgrounds	Method TO-15 6-L Summa canisters Grab sample collected at approx. 2:00 pm, or hottest time of day when access to the field is possible. 1-m sampling height, three sites “on playground/field”, one site for background	TO-15 GC/MS (gas chromatography/mass spectrometry)	Primary: Methyl-isobutyl-ketone Secondary: 55 other alkane, aromatic, oxygenated, and halogenated compounds

Table 1. Summary of Sample Collection and Analysis Methods (cont'd.)

Sample Type	Sites	Sampling Method	Analytical Method	Target Analytes
Surface Wipe	Synthetic turf fields	ASTM E1792 wipes (Ghost Wipes) and ASTM E1728 dust collection method. This is a standard wet wipe method. Collect wipes from three 1-ft^2 sites on turf fields. Wipes placed in precleaned 50-mL polyethylene container. Collect a second sample wipe next to each original sampling location for archival or possible metals bioavailability analysis	EPA Method 3050B, acid digestion with determination by EPA Method 6020A (ICP/MS inductively coupled plasma mass spectrometry) RBALP in vitro extraction (EPA Method 9200.1-86) for bioaccessible lead, and determination using ICP/MS by EPA Method 6020A	Primary: Pb, Cr, Zn Secondary: Al, As, Ba, Cd, Cu, Fe, Mn, Ni Pb
Tire Crumb Material (crumbs from playgrounds and infill material from synthetic turf fields)	Synthetic turf fields Playgrounds	ORD/NERL Research Protocol Collect samples of crumb material from three sampling locations on each playground or field. Add material to clean HDPE bottle. Collect a second set of samples for archival for possible metals bioavailability analysis or SVOC analysis.	EPA Method 3050B, acid digestion, and determination by EPA Method 6020A (ICP/MS) RBALP in vitro extraction (EPA Method 9200.1-86) for bioaccessible lead, and determination using ICP/MS by EPA Method 6020A	Primary: Pb, Cr, Zn Secondary: Al, As, Ba, Cd, Cu, Fe, Mn, Ni Pb

Table 1. Summary of Sample Collection and Analysis Methods (cont'd.)

Sample Type	Sites	Sampling Method	Analytical Method	Target Analytes
Turf Blades	Synthetic turf fields	ORD/NERL Research Protocol Collect loose blades from field surface in several sampling locations on the field, collect samples of different colors where possible, place blades in a clean 50-mL polyethylene container. Where there is sufficient material, archive material for possible metals bioavailability analysis.	EPA Method 3050B, acid digestion, and determination by EPA Method 6020A (ICP/MS) RBALP in vitro extraction (EPA Method 9200.1-86) for bioaccessible Pb, and determination using ICP/MS by EPA Method 6020A	Primary: Pb, Cr, Zn Secondary: Al, As, Ba, Cd, Cu, Fe, Mn, Ni Pb

analytes were included because they could be measured as part of the routine analysis of analytes of higher interest. As noted earlier, semivolatile chemicals, such as benzothiazole and PAHs, were of interest but were not measured in this scoping study because of the lack of readily available resources.

3.4 Proposed Sampling Sites and Sampling Locations

A study goal was to collect real-world environmental samples in four geographical areas across the United States (located near the four NERL laboratory locations) in late summer and fall of 2008:

- Athens, GA (EPA Region 4),
- Research Triangle Park, NC (EPA Region 4),
- Cincinnati, OH (EPA Region 5), and
- Las Vegas, NV (EPA Region 9).

The recommended approach relied on available NERL technical staff to implement the sampling protocol and the use of the laboratories' facilities as staging areas. In each geographical region, two sampling sites were to be defined: (1) a playground with crumb rubber material and (2) a synthetic turf field with tire crumb rubber infill. The proposed design would result in sampling at four playground sites and four synthetic turf field sites. Based on availability and access, alternate approaches were to be considered regarding the number of sites to be monitored in an area.

At a given sampling site (turf field or playground), four sampling locations were to be selected: three "on field" sampling locations and a background sampling location. The proposed "on field" sampling location configuration was an isosceles triangle, with one sampling location near the center of the playground or field and the other two at approximately equally distanced downwind positions. Actual deployment configuration was dependent on the site layout, planned activities, and wind direction. The background sampling location was intended to be within 100 m of the field or playground, over a natural grass surface when possible, and not in close proximity to likely pollutant sources. At each of the four sampling locations, all the following environmental samples and measures were to be collected (nominal, except where noted):

- integrated air PM_{10} sample for particle mass and metals composition,
- integrated air PM_{10} sample for particle morphology (size and shape),
- grab air sample for VOCs,
- wet wipe for metals composition (not at the background sampling location), and
- materials (tire crumb and turf fibers).

All air sampling was to be conducted with the inlet at a height of 1 m. Additional duplicate samples and measures were collected at one sampling location at each site. Standard meteorological measures (temperature, relative humidity [RH], and wind speed and direction) were taken periodically at each site sampling location. Activity levels (e.g., number of activities, number of individuals, type of activity) also were recorded. A 1-m^2 square plastic child barrier was set up around each sampling location to prevent the participants from running into or falling on the sampling equipment.

3.5 Sampling Considerations

There is no standard approach for determining the number of sample collection locations or the timing of sample collection at any one playground or synthetic turf field site. Key factors that were considered included

- potential variability of materials and chemical concentrations within a site;
- potential variability of activities at a site over time;
- meteorological conditions, particularly moisture, temperature, and wind speed and direction; and
- contribution of ambient background levels or nearby source contribution of the targeted chemicals to onsite measurements.

Each key factor is briefly described below, along with the proposed approach taken to minimize or characterize the impact on the resulting data.

3.5.1 Material Variability

Factor: Materials and chemical concentrations could vary within a site resulting in variation of targeted species across space and time at the playground or turf field. However, few data were available regarding the variability in contaminant concentrations within a playground or synthetic turf field site. Also, there was little information available to guide optimum locations for sampling at a site.

Proposed Approach: Three sampling locations were selected within the boundaries of the playground or turf field in areas close to the anticipated activity. These sampling locations were positioned such as to not interfere with normal activity or use. An additional background sampling location was selected near (~20 to 100 m) and upwind from the playground or turf field to characterize ambient background levels. This approach was implemented successfully for air samples with the exception that only two “on playground” sampling locations were set up at the playground because of the small size of the area. In addition, the tire crumb infill material and synthetic turf blades were collected where available, rather than at predetermined locations.

3.5.2 Activity Variability

Factor: Activities could vary over time at a site. Activity levels for the sites and sample collection locations could be highly variable within and between sites. This study was a scoping environmental measurement and methods development study. Therefore, no scripted activities and no personal measurements were implemented. Activity levels may affect air particle measurements. However, activity levels are unlikely to affect air VOC measurements, surface wipes, and tire crumb and turf blade material grab sampling. The normal use or activities at one site might require one or more of the samplers to be deployed near but not directly on the

playground or turf field. In this case, the samplers were placed as close to the activity as permitted.

3.5.3 Sample Volume for Detection Limit

Adequate sample volumes are needed to obtain reasonable detection limits for airborne particles and metals on particles. Therefore, equipment and methods for particle air sampling were selected to provide flow rates of 20 L/min over a nominal 8-h sample collection period. If the particle air sampling duration was applied to match an ongoing site activity of less than 8 h, then detection limits for those samples would be higher. A minimum sample collection time of 2 h for air particle samples was selected.

Proposed Approach: Where practical and permitted, air particle samples were collected in close proximity to where activities were ongoing, but without interfering with the normal activities or use of the playground or turf field. Information about extant activities at each site was collected. This approach was implemented successfully.

3.5.4 Meteorological Conditions

Factor: Meteorological conditions, particularly moisture, temperature, and wind speed and direction, might impact sample collection decisions and potential emissions. Meteorological conditions may influence air particle and air VOC measurements at playground and turf field sites. Wind will transport airborne pollutant species away from the site and will transport ambient pollutant species onto the site. Suspension and resuspension of particles likely will be affected by meteorological conditions. Temperature likely will influence the VOCs that might be emitted from tire crumb or other synthetic turf materials. With higher temperatures, higher levels of VOCs emissions would be anticipated.

Proposed Approach: This study was designed to collect air samples during those meteorological conditions that likely would result in the highest emissions (i.e., hot, dry, and calm days). Sampling was scheduled in August and September on days when no rain had occurred on the previous day and when no rain was anticipated, with anticipated wind speeds <10 mph. Air VOC samples were collected during the hottest time of day (~2 p.m.) at each “on field” or “on playground” sampling location at the site. Air sampling locations were selected, where possible, to offset potential changes in wind direction. Portable meteorological measurement stations were not deployed. Basic information about meteorological conditions (temperature, wind speed, and approximate wind direction) was collected at each site using a handheld measurement device. In general, this approach was implemented successfully.

3.5.5 Background Contribution

Factor: Ambient background pollutant levels could contribute to onsite measurements, particularly for air samples. Ambient contaminants also may contribute to the total burden at the playground or turf field as a result of aerosol or dust deposition.

Proposed Approach: At each playground or synthetic turf field site, one background sampling location was collected upwind from the playground or turf field. A set of air samples identical to the other sample collection locations was collected at the background sample collection location. The resulting data were intended to be used to characterize the potential contribution of ambient or background air contaminants to the playground or turf field. This approach was implemented successfully.

4. Methods

4.1 Air VOC Samples

Grab air samples for VOCs were collected using evacuated 6-L Summa-polished stainless steel canisters during the hottest time of day (~2 p.m.). This collection time was selected for likely highest air and surface temperature conditions promoting VOC emissions. Air temperature and surface temperature were measured and recorded at the time the samples were collected. Each sample was collected by opening the canister valve and allowing the evacuated canister to fill with air over an interval of approximately 20 s. The canister valve then was closed, and the canisters stored at ambient temperature until analysis. The canister samples were analyzed at the EPA Region 1 Office of Environmental Measurement and Evaluation for 56 VOCs by gas chromatography/mass spectrometry (GC/MS) following EPA Method TO-15.

4.2 Air PM_{10} Particle Samples for Mass and Metals Concentrations

PM_{10} is defined as airborne particulate matter with an aerodynamic size less than 10 μm. Ambient air was sampled at a nominal flow rate of 20 L/min (LPM) using metered, direct-current-supplied active samplers (SKC-HV-30 air pumps) and Harvard Impactor inlets (Air Diagnostic and Engineering), enabling PM_{10} mass loading on 47-mm Teflo filter media (Williams et al., 2008). Air monitoring was initiated for all monitors in quick order on their setup and calibration and continued without interruption through the monitoring event (day). At the conclusion of the sampling event, filter samples were recovered, stored in sealed transportation containers, and returned to the laboratory under ambient temperatures. The sampler ending flow rate was checked.

Filters were returned to the NERL Research Triangle Park, NC, gravimetric weighing facility, which operates under Federal Reference guidelines for temperature and relative humidity specifications (22 ± 0.5 °C, 35 ± 1% RH). The filters underwent a 24-h equilibration period prior to mass loading determination (Chen et al., 2007). Filter mass loadings were determined as the difference between presampling (tare) weights and those obtained following postsampling using a Sartorius MC 5 microbalance. The differential mass loading and data pertaining to the total volume of air sampled through each individual filter then was used to calculate the air mass PM_{10} concentration in units of micrograms per cubic meter for each sampling location. Immediately following gravimetric analysis, the PM_{10} mass concentration filters were released to the NERL X-ray fluorescence (XRF) laboratory for metals analysis. Metals analysis was performed for 44 selected metals using the NERL's unique Lawrence Berkeley National Laboratory-designed spectrometer (Williams et al., 2008).

4.3 Air PM_{10} Particle Sample Collection for Scanning Electron Microscopy

Sample collection for assessing air particle morphology and selected particle metals composition using SEM was conducted similarly to the primary PM_{10} mass and metals sample collection method. Identical SKC HV-30 pumps and similar Harvard Impactor samplers were used, the only differences being the operation of the units at a lower flow rate (10 LPM) to overcome observed filter pressure drop issues affecting pump battery life and run time. Specialized 37-mm polycarbonate filter material (Nuclepore) needed for SEM analyses was used.

4.4 Surface Wipe Sample Collection—Synthetic Turf Fields

Surface wipe samples were collected at synthetic turf field sites using a wet (water) wipe (Environmental Express, Ghost Wipe No. 4210) conforming to American Society for Testing and Materials (ASTM) E1792-03 requirements. Samples were collected at times when it was safe to

do so with regard to any activities occurring on the field. Sample collection time was not critical for these samples. Two co-located samples were scheduled for collection at the three ”on field” sampling locations. No background sampling location wipe sample was collected. Samples were collected following the ASTM E1728-03 method, a standard wet-wipe method for collecting dust from indoor floor surfaces that used water as the wetting agent. Specifically, a 1-ft^2 template was placed on the surface of the field. Using clean, powderless plastic gloves, the field sampling technician removed the wet wipe from the foil packet. Using one side of the wipe, the turf surface was wiped in a U-shaped pattern within the template area. After folding the wipe in half to get a fresh wipe surface, the area was wiped again in a U-shaped pattern perpendicular to the first wipe pattern. The wipe was then folded in half again and the edges near the interior portion of the template were wiped. Finally, the wipe was folded again and placed in a precleaned 50-mL polyethylene tube (Environmental Express, Disposable Digestion Cup No. SC475) for storage. The tube was tightly capped and transported at ambient temperature to the laboratory, where the samples were placed in a freezer at -20 °C.

4.5 Tire Crumb Infill Material Sample Collection—Synthetic Turf Fields

Tire crumb infill material was collected at the synthetic turf field sites. Samples were collected from one or more areas primarily based on availability of infill material (small tire crumb granules) at the surface of the field. These sampling locations did not necessarily correspond to the air particle sampling sites. Samples were collected at times when it was safe to do so with regard to any activities occurring on the field. Sample collection time was not critical for these samples. No background sample was collected. Infill material was scooped into a precleaned 50-mL polyethylene tube (Environmental Express, Disposable Digestion Cup No. SC475) for storage. The tube was tightly capped and transported at ambient temperature to the laboratory, where the samples were placed in a freezer at -20 °C.

4.6 Blade Material Sample Collection—Synthetic Turf Fields

An attempt was made to collect samples of the loose “grass blades” at synthetic turf field sites. No destructive sample collection was allowed, so blades were not cut or harvested from the turf fields. Where possible, samples were to be taken for each color of turf blades on the field. Sampling locations did not necessarily correspond to the air particle sampling sites. Samples were collected at times when it was safe to do so with regard to any activities occurring on the field. Sample collection time was not critical for these samples. No background sample was collected. Blades were collected using cleaned plastic forceps and were placed into a precleaned 50-mL polyethylene tube (Environmental Express, Disposable Digestion Cup No. SC475) for storage. The tube was tightly capped and transported at ambient temperature to the laboratory, where the samples were placed in a freezer at -20 °C.

4.7 Tire Crumb Material Sample Collection—Playgrounds

Two different approaches were used for sample collection at playgrounds. For the first approach, sample collection locations were approximately adjacent to the “on playground” sampling locations. Sample collection time was not critical for these samples. No background sample was collected. Tire crumb material was intended for collection from an approximate 4” x 4” square, with material collected from the surface down to ground level at each site. Material was collected using forceps or another appropriate tool, and crumbs were placed into a 250- or precleaned 500-mL, high-density polyethylene wide-mouth bottle (SciSpec Scientific Specialties Service, Inc, No. 353008 or No. 353016) for storage. The bottle was tightly capped and transported at ambient temperature to the laboratory, where the samples were placed in a freezer at -20 °C. At the second playground, a simple collection of tire crumb rubber material was performed. Samples were placed in polyethylene bags and were mailed to the laboratory.

Once received there, the samples were placed into high-density polyethylene bottles and stored in a freezer at -20 °C.

4.8 SEM Sample Preparation and Analysis

4.8.1 Sample Preparation

Ambient samples: 5 mm x 5 mm sections were cut from each polycarbonate filter using a stainless steel scalpel. Each section was affixed to a standard 12-mm aluminum specimen stub using a double-sided, sticky C tab. The samples were then coated with ~200 Å of C to minimize sample charging by the electron beam during SEM analysis.

Source material samples: Individual crumbs from the bulk material sample, typically 2 to 3 mm in size, were deposited “as is” on a sticky C tab. Source particles closer in size to the ambient sample were generated by shaving pieces from larger crumbs using a stainless steel razor blade. Source samples were coated with ~200-Å film of conductive C to minimize charge buildup on the sample during SEM analysis.

4.8.2 SEM Sample Analysis

Samples were analyzed by SEM and Energy-Dispersive X-ray Spectrometry (EDX) using the Personal SEM (R.J. Lee Instruments Ltd.) in the NERL Electron Microscopy Laboratory. Manual SEM/EDX analysis was first conducted on the bulk tire crumb source samples. Chemistry and morphological features characteristic of the tire crumb material were identified to help identify tire crumb particles in the ambient samples. Ambient samples were analyzed by computer-controlled SEM (CCSEM/EDX). Instrument parameters for the CCSEM analyses included 20-kV accelerating voltage, backscattered electron (BSE) imaging mode, 16-mm working distance, and zero tilt. The BSE mode yields a more uniform background than the secondary electron (SE) mode, necessary for computer-controlled SEM, but at the expense of some loss in sensitivity for small carbonaceous particles; carbonaceous tire crumb particles about 1 μm or smaller can be difficult to distinguish from the polycarbonate filter substrate in CCSEM analyses. Thus, small carbonaceous particles may be underreported in these analyses.

The CCSEM analysis was set up to analyze particles with average diameters between 1 and 20 µm. Few particles >10 µm, however, were observed in any sample. All particles within this size range were sized automatically and analyzed by EDX for chemistry. Based on the analyses of the tire crumb source samples sulfur (S), Zn, and C were identified as possible indicators of tire crumb material. Rules were developed to optimize the search for tire-crumb-like particles by extending the X-ray analysis time (10 s) and saving low-resolution images for all particles containing S, Zn, or C. Images and spectra for these particle types were reviewed manually offline, and particles were judged subjectively to be either tire-crumb-like, or not tire crumb material based on the particle morphology and chemistry.

Only a small fraction of the 6.7 cm^2 deposit area of each ambient filter was analyzed by CCSEM, typically about 1 mm^2, to complete each analysis in a reasonable time. Following CCSEM analyses, the EDX spectra and images of the particles of interest were reviewed manually, particles were relocated in the SEM for further examination, and suspected tire crumb particles were flagged.

4.9 Surface Wipe, Tire Crumb, and Turf Blade Sample Metals Analysis

Surface wipe samples, tire infill, tire crumb, and turf blade samples were received and prepared for analysis. Detailed sample descriptions were recorded because it was observed that the blade, infill, and crumb samples were not homogeneous. The playground tire crumb sample pieces were quite large and heavier than the normal sample size used for Pb in vitro

bioaccessibility extractions (typically 1 g). Five turf blade samples were not processed because they did not meet the minimum sample size of 0.7 g.

Sample Selection and Processing. For wipe samples, the entire wipe was used after removing any obvious turf blades or pieces of the infill material. For the crumb rubber infill samples from synthetic turf fields, 1.0 g aliquots were weighed out after rotating the field collection tubes in the x, y, and z axes for 1 min. For synthetic turf blade samples, the samples were processed with consideration of blade color. If more than one color of blade was present in the sample, representative blades of each color were selected for extraction. For the crumb rubber samples from playgrounds, pieces that appeared representative of the entire sample were chosen for extraction. In the situation where all pieces were very heavy, the piece closest to 1 g was used. A decision was made not to cut the samples as that would introduce fresh unaged surfaces, which potentially could impact the Pb bioaccessibility of the sample. Duplicate sample aliquots were chosen for extraction and spiking where there were adequate quantities.

Sample Extraction. The samples were treated as "soil" for the scoping study. Existing extraction procedures already in place were used. A consecutive extraction approach was taken because of the small number and amount of samples collected in the field.

First, the Pb in vitro extraction procedure EPA 9200.1-86 May 2008 "Standard Operating Procedure for an In Vitro Bioaccessibility Assay for Lead in Soil" was used. Two 10-mL aliquots from the 100-mL extract total were removed for analysis and storage. The extracts were adjusted to 2% nitric acid (HNO_3; v/v) prior to analysis.

To obtain total leachable metals, SW-846 Method EPA 3050B "Acid Digestion of Sediments, Sludges and Soils" was used next. The method was used as written with the following minor modifications.

- After quantitative transfer of the 80 mL of Pb in vitro extract and solids from the in vitro extraction bottles to 250-mL glass beakers, 5 mL of concentrated HNO_3 was added to the in vitro extracts, and the extracts were reduced in volume to 5 mL on a hot plate.
- A maximum of 2 h of acid refluxing was performed (similar to the hot block option extraction time). Neither the tire crumb infill nor tire crumb samples from playgrounds completely dissolved.
- Samples were filtered through a Whatman 25-mm GD/X 0.45-µm cellulose acetate membrane syringe filter, as centrifugation was not adequate to separate the particulates from the solution for analysis.
- Final samples extracts for EPA Method 3050B were in 5% HNO_3 (v/v).

Analysis by ICP/MS. A new X-Series II quadrapole ICP/MS was designated as the preferred instrument despite it still being in "start-up" mode. Therefore, instrument, software, and data processing routines were developed and evaluated concurrent with the samples' analysis. After dilution, the in vitro extracts were 2% HNO_3 (v/v). The EPA 3050B extracts were received as 5% HNO_3 (v/v), and all subsequent dilutions were made by weight with 5% HNO_3 (v/v).

Quantitative analysis for total extractable mass concentration was performed for the primary metals of interest: Cr, Pb, and Zn. In addition, the metals aluminum (Al), arsenic (As), barium (Ba), cadmium (Cd), copper (Cu), iron (Fe), manganese (Mn), and nickel (Ni) were reported; however, QC assessment was not as extensive for these metals.

The instrumental details for the Thermo X-Series ICP/MS are shown in Appendix B as follows: Table B-4 lists the operating parameters, Table B-5 lists masses used and interference correction information, Table B-6 lists the calibration standards used, and Table B-7 lists method detection limits.

The sample extract analysis followed procedures outlined in EPA SW-846 Method 6020A (http://www.epa.gov/epawaste/hazard/testmethods/sw846/online/index.htm). Instrument performance indicators are the QC solutions listed in Appendix B, Table B-8. For samples that

needed multiple dilutions to insure that all metals of interest were in the calibration range, the lowest dilution was used for a metal, where it did not exceed the top standard. Total extractable concentrations are calculated from the prorated combination of the in vitro extract concentrations and the EPA 3050B extract concentrations.

4.10 Pb Bioaccessibility Analysis

4.10.1 In Vitro Bioaccessibility Background Information

Methods for assessing Pb bioavailability in soil include in vivo animal studies, in vitro (referred to as bioaccessibility) studies, and mineralogical/speciation studies. In vivo studies quantify the metal present in various tissues and excreta of animals after an animal feeding bioassay is conducted. In vitro methodologies are physiologically based extraction tests designed to mimic the human gastrointestinal system. In vitro methods measure the bioaccessibility (e.g., solubility) of metals during a simulated gastric extraction process.

Bioavailability for this study is defined in the *Guidance for Evaluating the Oral Bioavailability of Metals in Soils for Use in Human Health Risk Assessment* (OSWER 9285. 7-80) as "The fraction of an ingested dose that crosses the gastrointestinal epithelium and becomes available for distribution to internal target tissues and organs (http://www.epa.gov/superfund/bioavailability/guidance.htm)." A related term pertaining to bioavailability assessment is *bioaccessibility*. Bioaccessibility refers to a measure of the physiological solubility of the metal at the portal of entry into the body (NRC, 2003). The U.S. EPA guidance document describes the methodologies for predicting lead bioavailability in soil using either an in vivo swine bioavailability bioassay or an in vitro bioaccessibility assay (IVBA). These methods have undergone extensive testing and evaluation, and they "are scientifically sound and feasible methodologies for predicting bioavailability of lead in soil" (OSWER 9285. 7-77). EPA recently published a standard operating procedure (SOP) for an in vitro bioaccessibility extraction for Pb that has been validated against the juvenile swine model (EPA Method 9200.1-86). The in vivo and in vitro methods described are specific to Pb-contaminated soils and Pb bioavailability. Currently, these methods have not been validated for testing other contaminants or media (e.g., tire crumb materials), and these have only been validated by EPA for Pb in soil.

4.10.2 In Vitro Pb Bioaccessibility Methodology

As noted above, validated in vitro methods did not exist for tire crumb samples when this study was conducted. The samples were extracted according to EPA Method 9200.1-86 May 2008 "Standard Operating Procedure for an In Vitro Bioaccessibility Assay for Lead in Soil." This SOP defines the proper analytical procedure for the validated in vitro bioaccessibility assay for Pb in soil (soil which has been homogenized and processed for optimal reproducibility) to describe the typical working range and limits of the assay and to indicate potential interferences. Users of this SOP are cautioned that deviations in the assay method may impact the results (and the validity of the method). Two 10-mL aliquots were removed from the 100-mL extract for analysis and storage. Samples were analyzed by ICP/MS following procedures outlined in EPA SW-846 Method 6020A.

Calculations. The amount of Pb in the in vitro bioaccessibility extraction is calculated by multiplying the extract concentration by the total volume of the bioaccessible extract, which was 100 mL. The in vitro percent bioaccessibility values were determined by dividing the amount of Pb extracted in the in vitro extraction by the total extractable amount of Pb in the sample and multiplying by 100.

4.11 Meteorological and Activity Information

Meteorological information, including air and surface temperatures, wind speed, and wind direction information was collected periodically during each monitoring period when integrated air sampling was conducted. Air and surface temperatures were always measured at the time of air VOC sample collection. Meteorological measurements were made using a handheld Kestral 3000 device. This portable device was used so that multiple measurements could be made at various sampling locations on and around a site. Surface temperatures were made by laying the device on the field or playground surface and waiting for the temperature reading to stabilize. Activities occurring at the synthetic turf field and playground locations, if any, were noted periodically during each monitoring daytime period.

5. Quality Control and Quality Assurance

Appendix B includes the data resulting from the QC/QA procedures implemented in this study and as outlined in the approved QA project plan developed for this study (U.S. EPA 2008). The following narrative summarizes these results.

5.1 Air VOC Quality Control

Air VOC QC results are shown in Tables B-1, B-2, and B-3. Potential background contamination in the sampling and analysis procedure was assessed using field and laboratory blanks (Table B-1). Field blanks were 6-L canisters filled with clean air at the laboratory and transported and stored with the samples collected at three sampling locations. Potential background in the laboratory was assessed using laboratory blanks that were clean air delivered to the analytical system. A laboratory blank was analyzed with each of the five sets of samples. Except for methyl ethyl ketone (MEK), no analytes were detected in any laboratory blank. MEK was measured at levels below the method detection limit in two of the five laboratory blanks. MEK was the only analyte detected in two of the three field blanks, at levels that were about 5 to 10 times lower than the concentrations measured in air samples. The third field blank contained numerous target analytes, often at concentrations exceeding those measured in the samples. For example, the concentration of benzene was 1.1 ppbV, and the concentration of toluene was 29 ppbV. It is possible that this canister had a leak and was contaminated during the storage and transport process. The pressure of each evacuated canister used for sample collection was measured prior to collecting the sample to ensure that the canister did not leak. Two canisters intended for sampling were found to be at ambient pressure prior to use and were not used for sample collection. It is possible that this field blank canister also had a leak, but, because it was filled to ambient pressure at the laboratory, it was not possible to directly assess this prior to field deployment.

Recovery of target analytes (Table B-2) was assessed through the analysis of field and laboratory controls. Field controls were 6-L canisters filled with air fortified with a subset of 30 target analytes. These field controls were transported and stored with the samples collected at three sampling locations. The same mixture of analytes also was analyzed as three laboratory controls to assess recoveries at the analytical step. Except for 1,1,1-trichloroethane and 1,2,4-trichlorobenzene, the mean recoveries of target analytes in field and laboratory controls were within the range of 84% to 114%. The mean recoveries for 1,1,1-trichloroethane and 1,2,4-trichlorobenzene in field controls were 125% and 62%, respectively.

Sampling and analysis precision was assessed using duplicate sample collection and repeat analysis of samples in the laboratory (Table B-3). Duplicate samples were collected at the same site and within a minute of the collection time of the primary sample at three sampling locations to assess the precision of the sampling and analysis procedures. Air collected in sample canisters at three sampling locations was analyzed a second time to assess laboratory analysis precision. Laboratory precision was assessed for 11 analytes with sufficient measureable results. Mean relative percent differences (RPDs) ranged from 2.9% to 15.6% for repeat analyses. Field sampling and analysis precision was assessed for 12 analytes with measurable results. For eight of those analytes, mean RPD values ranged from 1.8 to 21.1%. The mean RPD values were higher for four analytes, including hexane (59.7%), meta- and para-(m&p)-xylenes (38.4%), toluene (85.8%), and methylene chloride (32.4%). Two of the duplicate samples had concentrations of hexane, toluene, and m&p-xylenes that were much lower than their corresponding samples. As discussed below, these two field samples also had higher concentrations of these three analytes than the other samples collected at different sites at the same sampling locations. It is possible that these two field samples were contaminated, resulting in the poor measurement precision.

5.2 Air PM_{10} Mass Quality Control

A single certified flow calibration device (Bios) was used to document the set point and final flow rate of each sampler deployed in this effort. Flow rates, start and stop times, and sample identification notations were logged into predesignated data collection sheets employed for the field effort. A two-party check system was used during the field sampling effort to ensure that proper recovery of this data was performed, and that sample identification was correct. Two-party checks involved the primary researcher making the initial notation with the reviewer (second party) checking the notation independently for correctness. In addition to the data review conducted in the field, duplicate (collocated) samples were collected during each monitoring episode. This involved setting up a second monitoring station beside the original unit at one of the designated site sampling locations (A,B,C,D). The duplicate sampler was run under the same conditions as the primary unit, and its data were used to determine the precision of the employed methodology. Likewise, field and laboratory blank samples were utilized. Laboratory blanks (filter samples from the same single lot of filters used in the study) were maintained in the gravimetric laboratory to determine the amount of filter mass changes under control conditions. Similarly, field blank samples were deployed in the field at all sites. These samples were transported to the field, placed in the sampling apparatus but did not have any volume of air pulled through them. Filters treated in such a manner would represent the "artifact" mass associated with the sampling effort itself. Following the review of the data validation component of this study, it was determined that both the laboratory blanks and the field blanks had consistently insignificant quantities of mass loadings (≤2 $\mu g/m^3$), and, therefore, no blank correction was performed on the sample data. Results from comparisons of the field duplicate samples indicate that precision errors ≤10% or mass concentration differences of ~1 to 2 $\mu g/m^3$ were observed between replicates across all sites. All of these are highly acceptable values relative to normal data quality indicators for field monitoring efforts.

5.3 Air PM_{10} Metals Quality Control

The NERL XRF laboratory employs a sophisticated QA/QC review of instrumentation during all analyses. For example, the unit associated with this analysis underwent audit trials during the sample analysis runs. Such audits, using National Bureau of Standards or other reference materials, provide the means to determine the accuracy of the current instrument calibration, as well as other parameters. The instrument has to have both precision (±5%) and accuracy (±10%) values from such trials to be considered operational. All such parameters were achieved for the reported analysis results.

5.4 Air PM_{10} SEM Quality Control

As previously described for the PM_{10} gravimetric sample collections, field checks were conducted pre- and postsampling relative to flow rates. Duplicate samples were collected at every regional site to assess precision. The two-party review system again was used to ensure proper documentation of field data collections. Laboratory and field blanks were obtained and used to assess data quality (reported in Appendix D. These samples indicate that no sample handling or storage issues impacted SEM data quality.

5.5 Wipe, Tire Crumb, and Turf Blade Sample Quality Control and Quality Assurance

5.5.1 Instrument Performance

Data summarizing the ICP/MS operating parameters, calibration, and method detection limits are provided in Tables B-4 through B-7. Table B-8 provides the ICP/MS criteria for acceptable data. All ICP/MS instrument QCs met the criteria shown in Table B-8 with the

exception of one serial dilution result for Zn (15%) and one serial dilution result for Al (26%) that exceeded the 10% target value. Additional data regarding the results of instrument duplicate aliquot analysis, postdigestion spike recoveries, and agreement between serial dilutions are provided in the sections below.

5.5.2 Recoveries

Extraction performance indicators consisted of recoveries from solution spikes and spikes of sample media (Tables B-9, B-10, and B-11 and National Institute of Standards and Technology (NIST) Standard Reference Material (SRM) 2710 spikes (Tables B-12 and B-13). For the eight spikes prepared in the extraction reagent blank (Table B-10), recoveries for Cr, Pb, and Zn were all above 92%. Results for analyte recovery from solutions spiked onto the media of interest varied by media (Table B-11). The Ghost wipes were a uniform media. Recoveries for the three Ghost wipe spiked samples for Cr, Pb, and Zn were greater than 93%. For the tire crumb rubber infill and tire crumb material from playgrounds, there was considerable heterogeneity of the material. There was a visual difference between the sample aliquot used for spiking and the aliquot designated as “sample,” which was used to correct for the sample’s contribution to the total spiked sample concentration. Recoveries for the four spiked tire crumb rubber infill samples for the three metals of interest varied from 16% to 553%. For the tire crumb samples from playground samples, recoveries range from 17% to 255%. It is probable that these recovery ranges reflect the variability in existing metal content across samples and the inability to correctly subtract the existing content uniformly without additional sample homogenization.

Extraction reagent blanks and Ghost wipe samples were spiked with NIST SRM 2710, where the values for Pb and Zn are certified, and the Cr concentration is provided as “information only” in Tables B-12 and B-13, respectively. For the six extraction reagent blanks spiked with NIST SRM 2710 (Table B-12), the average recoveries for Pb, Zn, and Cr were 87%, 76%, and 37%, respectively. For the three Ghost wipe samples spiked with NIST SRM 2710 (Table B-13), average recoveries for Pb, Zn, and Cr, were 87%, 79%, and 32%, respectively. According to the NIST SRM 2710 certificate addendum and EPA 3050B,the median recoveries for Pb, Zn, and Cr in 2710 using EPA 3050B are 92%, 85%, and 49%, respectively. Note that EPA 3050B is a not total digestion technique but designed to dissolve almost all metals that could become “environmentally available.” By design, metals bound in silicate structures normally are not dissolved by the EPA 3050B procedure, as they are not usually mobile in the environment.

5.5.3 Analysis of Blank Materials

Nine extraction reagent blanks (identified as “bottle blanks”), one with each batch of samples, were processed with the samples (Table B-14). The sample data are reagent blank corrected using the bottle blank for the specific batch. Contamination in bottle blanks used for correction may cause overcorrection for some samples on some metals. However, the field samples also may be subject to this apparently random contamination. Table B-14 shows some situations where some metals, such as Cr, Fe, Mn, and Ni, are quite high in the 3050B bottle blank data compared to other bottle blank concentrations. The in vitro bottle blanks overall had very low concentrations but also showed a few high values.

Five 3050B-only reagent blanks were prepared with processing beginning at the hotplate step. Data from these samples were not used for sample correction. Results were similar to the 3050B bottle blanks. However, one sample did show very elevated concentrations of Cd, Cr, Fe, Mn, and Ni.

Three laboratory and three field blank ghost wipes were analyzed as samples (Table B-15). The two sets of wipes show similar concentrations. The 3050B extracts also

showed a few very high concentrations. The data from these blanks were not used to correct the ghost wipe sample data.

5.5.4 Measures of Precision

Analytical precision was assessed through the repeat analysis of sample extracts. The RPD for repeat analyses was less than the <20% target for the eleven metals (Table B-9).

Sampling precision also often is assessed by the collection of duplicate (collocated) samples. For the surface wipe and tire crumb material collected in this scoping study, this type of precision assessment also may assess the homogeneity of the sample media. Results for analysis of duplicate aliquots of tire infill material from a sample container or from different pieces of tire crumb collected from a playground are reported in Table B-16. For some media, there was a large RPD. Given the good analytical precision, the large RPD for duplicate sample aliquots or pieces strongly suggests that the materials, as collected and analyzed in this study, were not homogeneous with regard to the total extractable amount of some metals.

5.6 In Vitro Bioaccessibility Analysis Quality Control and Quality Assurance

A series of procedures and limits were followed to ensure the quality of the in vitro extractions and analyses. These QA/QC protocols are reviewed below, and any occurrence of nonconformance is noted and addressed. QA/QC for the extraction procedure consisted of a series of QC samples (controls, control limits, and corrective actions), as listed in Table B-17.

All bioaccessibility QC results are summarized in Tables B-18 through B-24) and meet the criteria shown in Table B-18, with the exception of the RPD values for the tire crumb duplicates (Tables B-23 and B-24) that is believed to result from sample heterogeneity issues. This extraction method was designed specifically for soils that have been processed in a manner used to create homogeneous samples. The RPD between duplicate extractions of these samples ranged from 2.7% to 124% for the infill samples and 4% to 183% for the crumb samples. Duplicate extractions of the wipes and blades were not possible either because there was a unique sample (wipes) or insufficient sample quantity (blades).

For the eight Pb spikes prepared in the in vitro extraction solutions (Table B-19), recoveries for Pb were all above 90%. The six NIST SRM 2710 extractions (Table B-20) resulted in an average RPD of 4.5% (range 0.4% to 8.9%). The RPDs for the three Ghost wipes spiked with NIST SRM 2710 (Table B-21) resulted in an average of 4.7% (range 3.5% to 6.2%). The NIST SRM RPD values are based on the mean in vitro bioaccessibility values of 75% for this SRM (EPA Method 9200.1-86).

Recoveries for blank Ghost wipes and tire crumb samples spiked with Pb solutions are listed in Table B-22. The media were extracted without spikes and used to correct for the sample's contribution to the total spiked samples. Recoveries for the four spiked infill samples for Pb ranged from 89% to 104%. Recoveries for the spiked crumb samples, ranged from 87% to 103% for Pb, whereas the recoveries for the spiked wipe samples ranged from 87% to 99%. Analysis of duplicate tire crumb infill and playground tire crumb aliquots (Tables B-23 and B-24, respectively) likely reflects the significant difference in heterogeneity of these samples.

5.7 Data Quality Assurance Review

Data generated in NERL/ORD laboratories in this scoping study were reviewed independently by a trained QA officer. The review included data generation, calculations, and transcriptions for a subset of the data. The Region 1 laboratory followed established laboratory QA/QC procedures in their analysis and review of air VOC results.

6. Results

6.1 Sampling Sites

The full study protocol (collection of all planned air, wipe, and material samples) was completed at two synthetic turf field sites (including repeated sampling on a second consecutive day at one site, F1). A reduced set of samples that did not include the integrated air particle sampling systems was completed at a third synthetic turf field site (F2). In addition, there were multiple synthetic turf fields at two sites (F2 and F3 at one site and F4, F5, and F6 at the other), and selected wipe and material samples were collected across different fields at these sites. The full study protocol, including collection of air samples, was completed at one playground (P1). However, because of the size of this playground, only two "on playground" sampling locations were operated instead of the three planned. Tire crumb material was obtained from a second playground, but no other sampling or site characterization was performed at this playground site. Information about each sampling site is provided in Table 2. The samples collected at each site are shown in Table 3.

Table 2. Sampling Site Information and Assigned Codes

Site	Type	Assigned Code
EPA Region 5, Field 1, Day 1[a]	Synthetic turf field	F1D1
EPA Region 5, Field 1, Day 2	Synthetic turf field	F1D2
EPA Region 4, Field 2[b]	Synthetic turf field	F2
EPA Region 4, Field 3	Synthetic turf field	F3
EPA Region 4, Field 4[c]	Synthetic turf field	F4
EPA Region 4, Field 5	Synthetic turf field	F5
EPA Region 4, Field 6	Synthetic turf field	F6
EPA Region 3	Playground	P1
EPA Region 4	Playground	P2

[a]Samples were collected at one synthetic turf field on 2 consecutive days.
[b]Two synthetic turf fields (F2 and F3) were part of the complex at this site.
[c]Three synthetic turf fields (F4, F5, and F6) were part of the complex at this site.

Table 3. Overview of the Types of Samples Collected at Each Site

Site	Air VOC	Air PM_{10} Mass	Air PM_{10} Metals	Air PM_{10} SEM	Surface Wipes	Tire Infill	Turf Blades	Tire Crumb
F1, Day 1	●	●	●	●	●	●	●	
F1, Day 2	●	●	●	●	●			
F2	●				●	●	●	
F3							●	
F4	●	●	●	●	●	●	●	
F5					●	●	●	
F6					●	●	●	
P1	●	●	●	●				●
P2								●

Fewer synthetic turf fields and playgrounds were monitored than originally planned, and at sites near only three of the four NERL facilities. This was primarily because of difficulties in identifying and arranging access to sites in combination with the logistical difficulties posed by the extensive array of equipment and skill required to operate the active particle sampling equipment at multiple sampling locations per site. Sampling at fewer sites had minimal impact on accomplishing the study goals, as the original design was very limited. Implementing the full protocol at only two synthetic turf field sites resulted in little impact in the methods evaluation study. Samples were collected at these two sites during relatively hot, dry days and with high activity levels (conditions favorable for the evaluation). The consecutive day measures at one site yielded additional data for assessing the methodology and understanding potential changes in site conditions from day to day. Sampling at only one playground site, although one with relatively high levels of activity, did provide insights regarding the practical issues regarding implementing the protocol at playground sites but resulted in limited data for the workgroup.

6.2 Site Characteristics

Descriptive information about each sampling site, including the age and type of material, maximum temperatures, wind speed, and activity information is provided in Table 4. Some anecdotal information may be relevant with regard to interpreting the study results. Sampling was conducted at field F1 on 2 consecutive days (F1D1 for day 1 and F1D2 for day 2). New tire crumb infill material recently had been applied to field F1. During the first day at field F1 (F1D1), heat thermals were observed coming off of the field during the hottest times of day, and there was a smell that generally is associated with tires or tire crumbs. There was considerable activity on this field throughout the day, including multiple physical education classes, as well as football and soccer practices. On the second day at field F1 (F1D2), the temperature was somewhat cooler, no thermals were observed, a similar smell was noted, and there were lower activity levels. Air PM sampling equipment was either on or immediately adjacent to field F1 during the activities. Fields F2 and F3 were adjacent fields at the same regional site. There was no activity at these fields during the monitoring period; therefore, no air PM samples were collected. Fields F4, F5, and F6 were collocated at another regional site. Air PM samples were collected on the sidelines of field F4. There was sporadic moderate activity on field F4 and on the immediately adjacent field (F5) during the monitoring day, including physical education classes, flag football, and a soccer game. One air PM sampling location was placed between fields F4 and F5. Two air PM sampling locations were placed on the opposite field F4 sideline based on wind direction at the beginning of the monitoring. The wind shifted later in the day and may have transported VOCs and particles to these two sampling locations (particularly to sampling location A) from the adjacent parking deck and nearby road with moderate commuter traffic. At playground P1, the playground was used by up to 60 preschool and early elementary students twice during the school day, and sampling continued for approximately 90 min into after-school use by approximately 12 to 20 students. The tire crumb material at playground P1, with embedded and visual fibers, was prepared and provided by a local supplier.

The air monitoring equipment setup at one sampling location at site F1 is shown in Figure 1, wipe sampling is shown in Figure 2, the turf blade and tire crumb infill at the surface is shown in Figure 3, and the multiple colors of turf blade are shown in Figure 4. A laboratory close-up of a sample vial containing tire crumb infill granules collected at site F2 is shown in Figure 5. Tire crumb material at site P1 is shown in Figure 6, and a laboratory close-up of this tire crumb material, with exposed fibers, is shown in Figure 7. A laboratory close-up of the “wood bark” tire crumb material collected at site P2 is shown in Figure 8.

Table 4. Site Information

Site	Surface Age	Type of Surface Material	Temperature at Time of Air VOC Sample Collection[a]	General Activity Levels on Monitoring Day
F1 Day 1 (F1D1)	2 years[b]	Polyethylene turf blades[c]; green field, red end zones, black and white lines; with granular tire crumb rubber infill	32 °C Air above field 50 °C Field surface Wind 2-11 mph	Est. number: 20-70 at a time Est. duration: 45-120 min at a time
F1 Day 2 (F1D2)	2 years[b]	Polyethylene turf blades[c]; green field, red end zones, black and white lines; with granular tire crumb rubber infill	35 °C Air above field 46 °C Field surface Wind 1-6 mph	Est. number: 20-70 at a time Est. duration: 30-45 min at a time
F2	4 years	Polyethylene turf blades[c]; green field, red center circle, white lines; with tire crumb rubber infill	28 °C Air above field 44 °C Field surface Wind 1-11 mph	Number: 0 Duration: 0
F3	5 years	Polyethylene turf blades[c]; green field, red center circle, white lines; with tire crumb rubber infill	—[d]	—
F4	4 years	Polyethylene turf blades[c]; green field; yellow and white lines; with tire crumb rubber infill	30 °C Air above field 44 °C Field surface Wind calm (2 mph)	Est. number: 10-35 at a time Est. duration: 45-120 min at a time
F5	3 years	Polyethylene turf blades[c]; green field, yellow and white lines; patched area appeared to be green nylon turf blades[c]; with tire crumb rubber infill	—	—
F6	2 years	Polyethylene turf blades[c]; green field, yellow and white lines; with tire crumb rubber infill	—	—
P1	4 years	Shredded tire material; black color; much of the tire crumb had fiber material still included.	30 °C Air above playground 36 °C Playground surface Wind calm (1 mph)	Est. number: 12-60 at a time Est. duration: 30-90 min at a time
P2	Not known	Tire crumb material processed and formed to simulated bark appearance; multiple green and brown colors.	—	—

[a]VOC air samples collected at hottest time of day (~2 p.m.).
[b]Additional new tire infill applied during summer prior to sampling.
[c]Type of turf blade material based on visual assessment (not confirmed through material analysis).
[d]Not measured or not monitored.

6.3 Sample Collection

The numbers and types of samples collected at each site are shown in Table 5. Air samples for VOCs were collected in evacuated 6-L Summa-polished stainless steel canisters at a 1-m sampling height. Four air VOC samples were collected at each of three synthetic turf field sites

Figures 1 through 4. Site F1 particle air samplers (top), surface wipe sample collection (left), green turf blade with black granular tire crumb (middle right), and multiple turf blade colors (lower right).

(F1, F3, and F4) with tire rubber infill material. Three air samples were collected at one playground site (P1) with tire crumb rubber material. Samples were collected at three different sampling locations (designated as A, B, and C, respectively) directly above each of the synthetic turf fields and at two different sites (A and B) directly above the playground. A background sample (designated as D) also was collected at each site a short distance upwind from the field

Figures 5 through 8. Tire crumb infill granules from site F2 (top left), shredded tire crumb at site P1 (top and bottom right), and tire crumb material from site P2 (bottom left).

or playground. With one exception, all air samples were collected at each site on 1 day and at approximately the same time of day. The exception was the collection of a set of four air samples on 2 consecutive days at one synthetic turf field. All grab air VOC samples were collected during the hottest time of day (~2 p.m.). In general, these grab air VOC samples were simple to collect, required little onsite collection time, and modest technical expertise. We found it was very important to verify the canister pressure prior to sampling to ensure that the evacuated canisters had not leaked prior to sample collection.

Integrated air PM_{10} samples for mass and metals concentration measurement, as well as separate integrated air samples for SEM analysis, were collected at a 1-m sampling height at the four VOC sampling locations at synthetic turf field F1 on 2 consecutive days, and on 1 day at field F4. Air PM_{10} samples were collected at the three VOC sampling locations on 1 day at playground P1. The limited sampling performed at playground P1 was based on the small space that did not allow the full complement of the normal sampling routine to be performed. In all events, active sampling locations were established quickly on the site, as well as from a background sampling location. Air monitoring was initiated for all monitors in quick order on their setup and calibration and continued without interruption through the monitoring event (daytime). This resulted in sample collections ranging from approximately 5.8 to 7.8 h and corresponding individual air volumes ranging from approximately 7.0 to 9.2 m^3 over the course of a sampling day. Collection of up to 10 air particle samples at each site required considerable equipment (enough to fill a van), considerable setup and retrieval time (approximately 1 h each), extensive staff time onsite (typically 8 to 10 h for two people), and moderate technical monitoring expertise. The monitoring approach, equipment, and sampling durations were selected to obtain

Table 5. Number of Samples Collected at Each Site

Site[a]	Onsite Samples	Background Samples	Duplicate Samples	Archival Samples	Field Blanks	Field Controls
Air VOC						
F1D1	3	1	1	—	1	1
F1D2	3	1	—	—	—	—
F2	3	1	—	—	—	—
F4	3	1	1	—	1	1
P1	2	1	1	—	1	1
Air PM_{10} for Mass and Metals						
F1D1	3	1	1	—	1	—
F1D2	3	1	1	—	1	—
F4	3	1	1	—	1	—
P1	2	1	1	—	1	—
Air PM_{10} for SEM						
F1D1	3	1	1	—	1	—
F1D2	3	1	1	—	1	—
F4	3	1	1	—	1	—
P1	2	1	1	—	1	—
Surface Wipes						
F1D1	3	—	3	3	1	—
F1D2	3	—	3	3	—	—
F2	3	—	3	—	1	—
F4	1	—	1	1	1	—
F5	1	—	—	1	—	—
F6	1	—	—	1	—	—
Tire Infill						
F1D1	3	—	—	—	—	—
F2	3	—	3	—	—	—
F4	1	—	1	—	—	—
F5	1	—	—	—	—	—
F6	1	—	—	—	—	—
Turf Blades						
F1D1	3	—	—-	—	—	—
F1D2	1	—	—	—	—	—
F2	3	—	—	—	—	—
F3	4	—	—	—	—	—
F4	1	—	—	—	—	—
F5	1	—	—	—	—	—
F6	1	—	—	—	—	—
Tire Crumb						
P1	2	—	1	2	—	—
P2	1	—	—	—	—	—

[a]F = synthetic turf field, D = day 1 or day 2, P = playground.

adequate limits of detection for PM_{10} mass and a range of metal analytes to ensure that levels typically found in ambient air would be measurable.

Surface wipe samples were collected at three “on field” sampling locations at synthetic turf fields F1 (on 2 consecutive days) and F2. At a third site, a single surface wipe sample was

collected from each of three fields (F4, F5, and F6), as the three fields making up this complex were of different ages. A standard wet-wipe method (ASTM E1728-03) that is used to measure residential surface dust Pb levels was employed for sample collection in this study. In the absence of a validated wipe method for synthetic turf surfaces, this method was selected for evaluation in this study. In general, the advantages of this method were the availability of standard wipe material and existing analytical methodology. In practice, samples could be collected by those with moderate technical expertise at multiple sampling locations in a relatively short period of time. However, the sampling procedure was not as simple as for smooth floor materials, with the synthetic turf blades requiring additional patience and control. The relationship between the dust collected on the wipe sample that comes from turf blades versus the dust from the infill and is available for human contact is not clear and may need further investigation. Most wipes also picked up a few pieces of the rubber infill material and turf blades. A decision was made to remove these relatively large discrete materials in the laboratory prior to extraction as these larger materials would be characterized as part of the additional material samples. It is not expected that removal of these large materials would impact the measurement of the small dust particles that the surface wipe sample is designed to collect.

Tire crumb rubber infill used in these synthetic turf field installations was collected from three sampling locations at fields F1 and F2 and at single sampling locations from each of three fields (F4, F5, and F6) at the third site. Sample collection could be completed in a short time by persons with minimal technical expertise. In this study, it was decided to collect infill material that was already available at the surface rather than by dislodging material trapped deep within the turf blades. This decision was based partly on avoiding potential damage to field components but primarily because the material on the surface was more available for potential human contact. However, infill material was not available uniformly across the field surface.

Synthetic turf blade samples were collected at all field sites in this study. The synthetic turf blades were not a primary interest in this study, as the characterization of this type of material is being performed by other organizations. However, samples of turf blades were collected to enable an improved understanding of the surface wipe measurements with regard to the potential differential contributions from the infill and blades. A decision was made not to perform destructive collection (i.e., there was no cutting of material from the fields). Instead, the collection relied on the availability of loose blades found at the surface of the fields. Collection and analysis decisions were complicated by the limited availability of loose blades and a later decision that a minimum of 0.7 g of material was required for analysis. Collection of blades of each color type was attempted. For fields F1, F2, and F3, the colors were collected separately and kept separate for analysis. None of the green blade samples from the site complex comprised of fields F2 and F3 achieved the “postsampling” requisite 0.7-g sample size, and they, therefore, were not analyzed. In retrospect, a decision to combine green blades from several different sampling locations would have enabled the analysis of a composite site sample. For fields F4, F5, and F6 the different colors for each field were mixed together in the sample to best achieve adequate sample sizes, while, at the same time, obtaining samples from fields of different ages.

Tire crumb rubber samples were obtained from two playground sites. The material used at the P1 playground consisted of shredded tire particles containing fibers, whereas the material from playground P2 was processed and colored to simulate tree bark. Collection of tire crumb material is a simple process. However, the material is relatively heterogeneous and it is not clear how many pieces or which pieces need to be collected for site characterization. It is also not clear whether it is most appropriate to collect tire crumb pieces at the surface that may have experienced different weathering and contact than underlying pieces. A further challenge is that relatively small amounts (1 g or less) are required for analysis because larger amounts may overwhelm digestion and analytical systems. Intact tire crumb rubber pieces are generally larger

than 1 g. A decision was made not to cut the tire crumb pieces because exposing unweathered surfaces might impact the Pb bioaccessibility measurement.

6.4 Summary Measurement Results

Tables 6 through 8 provide key data summaries for the synthetic turf field and playground sites. All of the individual site sample data are provided in Appendix C.

6.5 Air VOC Measurement Results (Appendix C, Table C-1)

Key highlights from the grab air VOC measurements are summarized below.

- Twelve of the 56 target VOC analytes were present in multiple samples. Thirty-seven of the 56 analytes were not detected in any sample. Seven of the remaining 19 analytes had detectable levels in only one or two samples.
- Measured VOC concentrations were generally low. No analyte concentration exceeded 1 ppbV in any sample. Detection limits ranged from 0.070 to 0.079 ppbV for most analytes, and 0.14 to 0.16 ppbV for 1,3-butadiene and m&p-xylenes.
- MIBK previously has been identified as a tire-related VOC. MIBK was present in three “on field” samples collected at one synthetic turf field (F1) on the first monitoring day when heat thermals were observed and in two “on field” samples on the second consecutive day of monitoring. MIBK concentrations were low (<0.2 ppbV) in all five samples. MIBK was not detected in the background samples collected near the field on either day. MIBK was not detected at any other site in this study.
- Concentrations of the other VOCs routinely measured over the field or playground sampling locations were similar to the concentrations measured in corresponding upwind background samples collected nearby, or they likely could be explained by documented local sources near the site.
- MEK was measured in all the study samples, with the “on field” MEK levels being similar to levels in the upwind background samples at each site.
- Hexane was present in most of the “on field” and background samples. At the F4 synthetic turf field, the hexane concentrations at all three “on field” sites were higher than the background site, but all concentrations were low (<0.2 ppbV).
- The aromatic analytes benzene, toluene, and m&p-xylenes are ubiquitous atmospheric pollutants and were present at measureable levels in most samples collected in this study.
- Benzene concentrations were similar for the background and “on field” samples at all sites. The highest benzene concentration (0.32 ppbV) was measured at location A on site F4. This concentration was higher than at sites B or C or the background site D. Other aromatic VOC concentrations also were elevated somewhat at this sampling location and site. Sampling location A was closest to a parking garage exit and may have been impacted by traffic and vehicle exhaust.
- Toluene, m&p-xylenes, and hexane concentrations at site P1 location B, and at site F1 location B, were higher than concentrations at the other sampling locations for these sites. The reason for this is not clear; however, elevated levels (>4 ppbV) of these compounds were measured in one field blank, and contamination of the sampling canisters cannot be ruled out. Both of these samples had a corresponding duplicate sample collected at location B. Concentrations of these three analytes were present in the duplicate samples at ratios ranging from 0.15 to 0.63 of the concentrations in the samples. In fact, the concentrations measured in the duplicate samples were similar to the concentrations measured in the other samples at each site, further suggesting that these two samples with slightly higher concentrations may have been contaminated.
- Several halogenated VOCs were measurable in all or most of the samples. These included carbon tetrachloride, methylchloride, methylene chloride, dichlorodifluoromethane (Freon 12),

Table 6. Summary Results for Selected Analytes in Air Samples Collected at Synthetic Turf Fields and a Playground

			Synthetic Turf Fields								Playground	
			F1D1		F1D2		F2		F4		P1	
Air Samples	**Analyte**	**Unit**	**On Field[a]**	**Back-grnd.[b]**	**On Field[a]**	**Back-grnd.[b]**	**On Field[a]**	**Back-grnd.[b]**	**On Field[a]**	**Back-grnd.[b]**	**On Play.[a]**	**Back-grnd.[b]**
Air PM Mass	Particle Mass	$\mu g/m^3$	27.8	29.5	29.8	29.5	—	—	31.8	28.6	26.7	14.2
Air PM Metals	Pb	ng/m^3	ND[c]	ND	7.7[d]	6.3	—	—	ND	ND	5.1[d]	ND
	Cr	ng/m^3	2.9	2.0	3.6	3.3	—	—	ND	ND	3.4	ND
	Zn	ng/m^3	10.8	23.8	11.8	11.6	—	—	31.4	21.7	104	10.5
Air VOCs	Methyl Isobutyl Ketone	ppbV	0.13	ND	0.12	ND	ND	ND	ND	ND	ND	ND
	Benzene	ppbV	0.09	0.07	0.08	0.09	0.11	0.12	0.20	0.12	0.09	0.09
	Toluene	ppbV	0.42	0.15	0.11	0.12	0.18	0.19	0.28	0.19	0.29	0.16
	m&p-Xylenes	ppbV	0.17	0.08	0.10	ND	0.07	0.08	0.14	ND	0.13	0.05
	Hexane	ppbV	0.21	0.06	0.08	0.08	0.08	0.05	0.14	0.05	0.30	ND
	Methyl Ethyl Ketone	ppbV	0.47	0.44	0.38	0.36	0.41	0.37	0.43	0.44	0.41	0.38
	Carbon Tetrachloride	ppbV	0.09	0.10	0.10	0.10	0.09	0.08	0.09	0.10	0.08	0.09
	Dichlorodifluoromethane	ppbV	0.52	0.55	0.50	0.56	0.56	0.51	0.48	0.54	0.53	0.54
	Methylchloride	ppbV	0.47	0.48	0.47	0.46	0.45	0.45	0.48	0.52	0.46	0.45
	Trichloro-fluoromethane	ppbV	0.26	0.28	0.26	0.27	0.27	0.25	0.24	0.30	0.26	0.26
	Trichloro-trifluoroethane	ppbV	0.08	0.08	0.08	0.08	0.08	0.07	0.07	0.15	0.07	0.07
	Methylene Chloride	ppbV	0.07	0.06	ND	ND	0.06	0.06	0.06	0.06	0.09	0.07

[a]Average of two or three “on field” or “on playground” measurements (any nondetect values were not included in the average).
[b]Single measurement from upwind background location.
[c]Not detected.
[d]Pb was measured in only one of three “on field” samples at F1D2 and one of two “on playground” samples at P1.

Table 7. Summary Results for Total Extractable Pb, Cr, and Zn in Samples Collected at Synthetic Turf Fields and Playgrounds

			Synthetic Turf Fields				Playgrounds	
			F1D1	F1D2	F2, F3	F4, F5, F6	P1	P2
Sample	**Analyte**	**Unit**	**Range**	**Range**	**Range**	**Range**	**Range**	**Range**
Turf Field Surface Wipe Samples	Pb	µg/ft^2	0.3-1.9	0.4-1.4	0.3-0.5	0.1-0.2	NC[a]	NC
	Cr	µg/ft^2	0.1-0.5	0.1-0.3	ND.[b]	ND-0.3	NC	NC
	Zn	µg/ft^2	21.3-43.3	26.4-40.6	9.2-19.3	4.3-13.6	NC	NC
Turf Field Infill Crumb Rubber	Pb	µg/g	13.1-34.7	NC	20.6-61.2	10.7-47.7	NC	NC
	Cr	µg/g	0.3-1.0	NC	0.4-0.9	0.3-1.0	NC	NC
	Zn	µg/g	5,050-19,200	NC	3,120-12,300	2,660-11,400	NC	NC
Turf Field Blades	Pb	µg/g	2.8-389[c]	NC	2.4-2.8[d]	2.1-701[e]	NC	NC
	Cr	µg/g	1.0-73.1	NC	1.2-1.9	3.7-177	NC	NC
	Zn	µg/g	316-730	NC	199-255	131-206	NC	NC
Playground Tire Crumb	Pb	µg/g	NC	NC	NC	NC	1.0-443[f]	3.4-7.8[g]
	Cr	µg/g	NC	NC	NC	NC	0.3-1.7	1.6-3.0
	Zn	µg/g	NC	NC	NC	NC	4,300-17,500	12,100-18,000

[a]Not collected.
[b]Not detected.
[c]Differences noted for different blade colors (red = 389 µg/g; white, green, and black all <4.3 µg/g).
[d]Analysis of red and white blades.
[e]Highest level (701 µg/g) found in a field with a repaired area; levels in blades from two adjacent fields ranged from 2.0 to 77 µg/g.
[f]Analysis of seven pieces of tire crumb; six of those pieces had Pb levels <50 µg/g.
[g]Analysis of two pieces of tire crumb.

Table 8. Summary Results for Estimates of Pb Bioaccessibility in Samples Collected at Synthetic Turf Fields and Playgrounds[a]

		Synthetic Turf Fields				Playgrounds	
Sample	**Analyte**	**F1D1 Range**	**F1D2 Range**	**F2, F3 Range**	**F4, F5, F6 Range**	**P1 Range**	**P2 Range**
Turf Field Infill Crumb Rubber	Pb	1.6%-9.6%	NC [b]	1.7%-7.6%	1.7%-10.1%	NC	NC
Turf Field Blades	Pb	2.3%-86.8%[c]	NC	38.7%-40.3%[d]	0.2%-54.4%[e]	NC	NC
Playground Tire Crumb	Pb	NC	NC	NC	NC	0.3%-10.7%[f]	1.8%-7.4%

[a]The in vitro bioaccessibility method has not been validated for these materials.
[b]Not collected.
[c]Differences noted for different blade colors (red = 2.3%, white and green = 40.9% to 43.0%, and black = 86.8%); also, the lowest bioaccessibility value (2.3%) corresponds to the sample with the highest total extractable Pb (389 µg/g).
[d]Analysis of red and white blades.
[e]Lowest bioaccessibility value (0.2%) corresponds to the sample with the highest total extractable Pb (701 µg/g).
[f]Lowest bioaccessibility value (0.3%) corresponds to the sample with the highest total extractable Pb (443 µg/g)

trichlorofluoromethane (Freon 11), and trichlorotrifluoroethane (Freon 113). In all cases, the levels in the “on field” samples were similar to levels in the upwind background sample at each site.

6.6 Air PM_{10} Mass Measurement Results (Appendix C, Table C-2)

PM_{10} concentrations observed across all of the sites ranged from approximately 24 to 33 µg/m^3. PM_{10} mass concentrations collected on or adjacent to synthetic turf fields were generally equivalent to concentrations in ambient air measured at the upwind background sites. Mass concentrations across a given synthetic turf field or playground were often consistent within themselves. That is, PM_{10} concentrations from field sampling locations A, B, and C at a given site often varied by only 2 to 3 µg/m^3, which was within the precision error typically observed for the duplicates. This mass consistency was generally true regardless of the range of activities taking place on the field and the proximity of such activities to a given monitor. Such a statement, however, cannot be made for the one playground site monitored. Comparison of data from the P1 site indicates an approximately 15 µg/m^3 higher PM_{10} mass concentration was obtained from the monitor located near the highest density of playground activity (location B).

6.7 Air PM_{10} Metal Measurement Results (Appendix C, Table C-3)

Air PM_{10} sample filters were analyzed for 44 metals. As part of the analysis, the statistical uncertainty of the measurement was determined; the measured metal concentrations must be at least three times the uncertainty concentration to be considered a measured result. Based on this assessment, the full list of 44 metals was reduced to 12 that are reported in Appendix C-3, including the primary analytes Pb, Cr, and Zn (see Table 6), as well as 8 other elements (Ca [calcium], Cl [chlorine], Cu, Fe, K [potassium], Mn, S, Si [silicon], and Ti [titanium]) with sufficient number of measurable results for assessment within and across sampling sites.

Measurement results from synthetic turf field F1 show that upwind background levels of Si, S, Cl, K, Ca, Ti, Cr, Mn, Fe, Cu, Zn, and Pb were similar to the “on field” concentration measurements at thee sampling locations (A, B, and C). This would indicate that the infill tire crumb rubber and other materials on the turf field examined in F1 (on both day 1 and day 2) provided little contribution to the measured metal concentrations associated with airborne aerosols. Slightly higher concentrations of Ti (~36%), Cr (~90%), Mn (~100%), Fe (~74%), Cu, (~57%), and Zn (~65%) were measured at the “on field” monitors relative to the upwind background sampling location at the F4 synthetic turf field. This site was bordered by both a busy urban commuter road, as well as a parking deck. Because of this, the additional contribution of some of the metals to the collected "on field” air samples, notably those that often are observed in near-roadway air samples (Fe, Zn, and Cu) might not be singularly reflective of contributions from a single source (i.e., this might be indicative of near-road influence, as well as of any contribution from any resuspended tire crumb rubber infill aerosol).

It would appear that the “on playground” samples associated with the P1 site had consistently higher levels of the 12 selected metals discussed above, as compared with the background site. For example, “on playground” aerosol metal concentrations for Si, Cl, K, and Ca were sometimes 50% to 700% higher, as compared with the background. These metals often are associated with crustal (soil) related sources. “On playground” samples had much higher levels of metals that might be of relevance to tire crumb rubber components. For example, Ti concentrations were more than four times higher for one “on playground” sampling location, with nonspeciated Cr concentrations (~3 ng/m^3) substantially higher than the background monitor.

Mn concentrations were ~7 times higher (15 ng/m^3), with Fe as much as 4 times more concentrated (~1,000 ng/m^3). Of particular interest are Zn levels, which were 8 to 11 times higher than background levels for the two “on playground” monitors (82 to 117 ng/m^3). On the

other hand, these metals also may be found in soils, so the relative contribution of tire crumb particles to the increased levels could not be determined readily from these results.

Pb concentrations were at measurable levels in only 3 of the 18 air PM samples collected in this study. These three samples had concentrations (≤7.7 ng/m^3) that were near the method detection limit. The maximum concentration of 7.7 ng/m^3 was measured in a sample collected at a synthetic turf field and, given the precision of the method, is considered indistinguishable from the corresponding background level (6.3 ng/m^3). A Pb level of 5.1 ng/m^3 was measured at one "on playground" sampling location; again, a level near the method detection limit. The samples for another "on playground" sample, its duplicate sample, and the background sampling location had Pb values below the method detection limit.

6.8 Air PM_{10} SEM Measurement Results (Appendix C, Table C-4)

Air PM_{10} samples were collected on filters at three sites with tire crumb material for SEM analysis. Air samples collected at two "on field" or "on playground" sampling locations and at one upwind background sampling location were analyzed for synthetic turf fields F1 and F4 and playground P1. In preparation for analyzing the air samples, samples of the tire infill material from a field and the crumb material from a playground were analyzed to determine whether metal or morphological "source profiles" could be identified that would assist in identifying tire crumb-related particles in the air samples. A detailed report describing the SEM analysis procedure and measurement results is provided in Appendix D. Key findings from the SEM analysis are described below.

- Prior to analyzing the air filter samples, particles were generated from the tire crumb materials collected at the turf fields and playground to try to identify a signature morphology and metals composition for tire crumb particles. These particles did not show a unique, easily identifiable X-ray spectrum for metals composition or supporting a definitive source attribution analysis. C and S were consistently present in the tire crumb particles. Zn usually but not always was observed in tire crumb particles, often at trace levels. Tire crumb particles from the source material varied considerably in morphology, making it difficult to identify a typical or characteristic tire crumb morphology.
- Very few fibers were observed in any of these air samples, and none could be attributed to tire crumb. This was true even for the playground site (P1) air samples, which had tire crumbs with exposed and embedded fibrous material.
- The ability to quantify the tire crumb concentration in these samples hinges on the tire crumb particles having a unique composition or morphology that would enable the analyst to identify tire crumb particles with a high degree of confidence. This does not seem to be the case for tire crumb particles collected in this study, as seen in the variety of morphologies and compositions on air filters.
- At the two synthetic turf fields, mass concentrations for postulated tire crumb particles were estimated to be only a very small fraction of the total PM_{10} mass concentrations measured at these sites. At the playground site, estimated mass concentrations for postulated tire crumb particles were a relatively small fraction of the total PM_{10} mass concentrations, but a higher fraction than was measured at the synthetic turf fields. However, the variability in tire crumb particle composition and morphologies introduces large uncertainties in these results.

6.9 Total Extractable Metals in Synthetic Turf Field Surface Wipe, Tire Crumb Infill, and Turf Blade Samples and Playground Tire Crumb Rubber Samples (Appendix C, Tables C-5 through C-8)

The total extractable measurement results for 11 metals in wipe, tire crumb, and synthetic turf blades collected in the scoping study are shown in Appendix C. Primary target metals were Pb, Cr, and Zn (see Table C-5), and metals of secondary interest included Al, As,

Ba, Cd, Cu, Fe, Mn, and Ni. Results from surface wipe samples collected at synthetic turf fields are shown in Table C-5, those for tire crumb infill from synthetic turf fields are shown in Table C-6, and those for synthetic field turf blades are shown in Table C-7. Results for tire crumb material at playgrounds are shown in Table C-8.

6.9.1 Surface Wipes from Synthetic Turf Fields (Table C-5)

Surface wipe samples were collected at different sampling locations from several synthetic turf fields. The sampling locations were in close proximity to the air monitoring "on field" locations. In some cases, duplicate samples were collected side-by-side. Some wipe samples were collected from different color turf blade areas at one site (F1) where there were large areas of different color turf blades. A wipe sample also was collected at the field (F5) with visually different turf materials. Total extractable metal measurement result highlights include those that follow.

- Total extractable Pb was less than 2.0 µg/ft^2 in all surface wipe samples collected at the synthetic turf fields in this study. Most results were less than 1.0 µg/ft^2.
- Many of the sample analysis results were similar to levels measured in field blanks, which had Pb values ranging from 0.14 to 0.54 µg/ft^2.
- The highest total extractable Pb value (1.9 µg/ft^2) was measured on a surface wipe collected at site F1 on red synthetic turf blades.
- Surface wipe samples collected side-by-side, in some cases, had similar total extractable Pb levels; in other cases, the differences in side-by-side measurements ranged up to approximately twofold. Some of the side-by-side measures taken at one turf field site (F1) were from an area of mixed turf blade colors.
- Surface wipe samples collected at different locations on synthetic turf fields had up to sixfold differences in total extractable Pb concentrations. The greatest differences appeared to be associated with wipes taken from areas with different blade colors.
- Total extractable Cr was <0.6 µg/ft^2 in all surface wipe samples.
- Total extractable Zn in surface wipe samples ranged from 4.0 to 43 µg/ft^2.
- Measurements of As were very low (≤0.1 µg/ft^2) and similar to amounts found on field blanks.
- Most Cd measurements were less than the method detection limit; the remainder were ≤0.025 µg/ft^2.

6.9.2 Tire Crumb Infill at Synthetic Turf Fields (Table C-6)

Samples of tire crumb infill granules were collected at different sampling locations from several synthetic turf fields. The sampling locations did not necessarily correspond to the sampling locations where the other samples were collected. In some cases, duplicate samples were collected side-by-side. In addition, second aliquots of material collected in each sample container were analyzed, so that there were two analysis results for each sample or duplicate sample.

It is important to remember that the methods for collection and analysis have not been validated. Total extractable metal measurement result highlights include the following.

- Total extractable Pb concentrations in tire crumb infill from synthetic turf fields ranged from 11 to 61 µg/g.
- There was considerable variability (up to an approximately fourfold difference) in total extractable Pb concentrations for different aliquots randomly taken from the same sample container.
- The variability among locations at a site and among different sites was similar to the variability in Pb measurement results for aliquots taken from the same container (up to approximately fourfold).
- Total extractable Cr concentrations ranged from not detected to 1.0 µg/g.

- Total extractable Zn concentrations ranged from 2,600 to 19,000 µg/g.
- The variability in Zn concentrations for aliquots taken from the same container was less than the variability observed in Pb concentrations.
- Concentrations of As ranged from not detected to 0.55 µg/g.
- Cd concentrations ranged from not detected to approximately 1.5 µg/g.

6.9.3 Turf Blades at Synthetic Turf Fields (Table C-7)

Characterization of the turf blade material was not a primary goal of this scoping study; the focus of this study was on the tire crumb components. However, these samples were collected and analyzed to help improve interpretation of the surface wipe measurements. It is important to remember that the methods for collection and analysis have not been validated for this material. Samples of synthetic turf blades were collected at different sampling locations from several synthetic turf fields. Where possible, samples of different colors were collected but, because of the small sample sizes, could not always be analyzed separately. The sampling locations did not necessarily correspond to the locations where the other samples were collected. Total extractable metal measurement result highlights are as follows.

- Total extractable Pb concentrations from synthetic turf blades ranged from 2.4 to 700 µg/g.
- The highest total extractable Pb concentration (700 µg/g) was measured from blades in a sample collected at a turf field (F5), which included an area that had apparently been repaired with a section of turf material visually different from the rest of the field. Mixed-color turf blade samples taken from two adjacent fields (F4 and F6) at the same site had Pb levels ranging from 2.0 to 77 µg/g.
- The second highest total extractable Pb concentration (389 µg/g) was measured in red blades at another turf field site (F1). Pb concentrations for green, white, and black blades collected from this same site ranged from 2.8 to 4.3 µg/g.
- Total extractable Cr concentrations ranged from 0.1 to 180 µg/g. The level of Cr generally appeared to be lower than but correlated with the corresponding Pb concentrations.
- Total extractable Zn concentrations ranged from 130 to 730 µg/g. Zn levels in white and black blades collected at one site (F1) were about twofold higher than in green and red blades at the same site and about three to five times higher than levels measured in blades from the other two synthetic turf field sites.
- Concentrations of As and Cd were less than 0.6 µg/g in all samples.

6.9.4 Tire Crumb Material from Playgrounds (Table C-8)

Samples of tire crumb pieces were collected at different sampling locations at two playgrounds. Seven pieces of crumb rubber from one playground (P1; shredded tires with exposed fibers) and two pieces from the second playground (P2; with simulated bark tire crumb material) were analyzed. It is important to remember that the methods for collection and analysis have not been assessed or validated. Total extractable metal measurement result highlights include those described below.

- Total extractable Pb concentrations in five pieces of shredded tire crumb from P1, the playground with fibrous materials, ranged from 1.0 to 6.3 µg/g. A Pb concentration of 46 µg/g was measured in a sixth piece, and 440 µg/g Pb was measured in a seventh piece, documenting the heterogeneity of Pb in these site samples.
- Total extractable Pb concentrations from two simulated bark tire crumb samples collected at a second playground (P2) were 3.4 and 7.8 µg/g.
- Total extractable Cr concentrations ranged from 0.3 to 3.0 µg/g.
- Total extractable Zn concentrations ranged from 4,300 to 18,000 µg/g.
- The variability in Zn concentrations was less than the variability observed in Pb concentrations.

- Concentrations of As ranged from 0.04 to 0.96 µg/g, except for a value of 15 µg/g that was measured in the same P1 crumb piece with the highest Pb level (440 µg/g Pb).
- Cd concentrations ranged from 0.09 to 10.5 µg/g, with the highest concentrations corresponding to samples with the highest Pb concentrations.

6.9.5 Lessons Learned with Regard to the Sampling and Analysis of Tire Crumb Materials

Again, there are no validated sample collection and analytical procedures for characterizing tire crumb materials for assessing potential environmental concentrations or potential exposures by various routes and pathways at synthetic turf fields and playgrounds. An objective of this scoping study was to apply an existing wipe sample collection method and analytical procedures developed for soil media and to assess their performance. A few of the lessons learned are described below.

- There was no evaluated protocol available for measuring tire crumb rubber constituents at turf fields and playgrounds. As such, this scoping study was conducted to evaluate the methods and identify key factors (e.g., resources, accessibility, practicality, activity levels) that would need to be considered in designing future studies. Some factors that may need to be considered for future research include the number and placement of sampling locations (i.e., how many samples at how many locations need to be collected and analyzed to adequately characterize a site), representative and duplicate wipe samples for turf fields with mixed colors, retaining or not retaining turf infill and fibers on wipe samples, representative material samples, the relationship between the wipe sample and material sample results.
- In some cases, the amount of material available for analysis was not optimal, generally a 1-g sample is specified in methods. For tire crumb material from playgrounds, most of the crumb pieces were much larger than 1 g. It was decided that the material would not be cut because that would open fresh surfaces that potentially would result in different extractable amounts. Decisions not to cut up samples prevented sample size matching to extraction procedure requirements and prevented homogenization procedures. In addition, the larger samples created some extraction and analysis problems with regard to the extraction vessel and need for multiple dilutions of some sample extracts. On the other hand, some samples of synthetic turf blades collected in this study were not adequate for analysis. Only nondestructive collection of loose blades was performed in this study. In future work, sample sizes and decisions regarding tire crumb subsampling should be considered.
- Information from this and other studies regarding the metals of most interest would improve analytical optimization, reporting, and the selection of appropriate QC materials.
- The heterogeneity of these samples create analysis and data interpretation challenges. For example, multiple dilutions and reanalyses of many samples were required to obtain measurements in the instrument calibration range. Based on excellent results from analytical QC analyses (serial dilution and postdigestion spikes), the new ICP/MS instrument used for this study appeared to produce quantitative total extractable results for the wipe samples, turf blades, tire infill, and tire crumb media for multiple metals with low detection limits.
- Spiking levels appropriate to the tire material and blade material concentrations need to be considered in future study designs to improve results. However, given the heterogeneity of the materials, it is not clear whether spiking samples to assess recoveries will be feasible. Spike recoveries need to be reevaluated with truly homogeneous samples to determine whether the extraction procedure or the sample heterogeneity was the source of variable recoveries during the scoping study.
- Sporadic contamination of laboratory bottle blanks was found, especially for metals that might be associated with steel. In this study, the blank result for each analysis batch was subtracted from measured results, following the standard procedure. In the future, blank correction could be based on the average of the bottle blanks, with the option of removing outliers.

Investigation is needed of possible sources of contamination and, perhaps, changing to a less "open" extraction process.

6.10 Pb Bioaccessibility Results (Appendix C, Tables C-9, C-10, and C-11)

6.10.1 Analysis of Turf Field Wipe, Tire Crumb, and Turf Blade Samples

The bioaccessible values for Pb in the field samples are provided in Appendix C. Because of the variability observed for different sample aliquots, duplicate samples, and analyses of multiple sample pieces, we have reported all analyses individually rather than averaging the results across the two measurements for each sample. It is important to recognize that different bioaccessibility procedures may yield different Pb bioaccessibility results. The EPA method employed in this study has been validated for Pb in soil, but no methods have been validated for tire crumb or synthetic turf blade materials. Highlights from the bioaccessability analyses include those below.

- Synthetic turf field tire crumb infill Pb bioaccessibility ranged from 1.6% to 10.7% (mean 4.7%; Table C-9).
- Synthetic turf field blade Pb bioaccessibility (Table C-10) ranged from 0.2% to 86.8% (mean 34.2%). The three samples with the highest total extractable Pb (77 to 700 µg/g) had the lowest Pb bioaccessibility values (0.2% to 2.3%). Gaining a clear understanding of this observation requires additional research.
- Playground tire crumb Pb bioaccessibility (Table C-11) ranged from 0.3% to 7.4% (mean 4.3%). The two samples with the highest total extractable Pb (46 and 440 µg/g) had the lowest Pb bioaccessibility values (both 0.3%). Gaining a clear understanding of this observation requires additional research.
- Up to a fourfold difference in Pb bioaccessibility was found between two aliquots of tire crumb infill analyzed from the same sample vial. Up to a 36-fold difference was found between the analyses of seven pieces of tire crumb material from the same playground. These results suggest substantial heterogeneity in Pb bioaccessibility from tire crumb rubber samples. Gaining a clear understanding of this observation requires additional research.
- The in vitro Pb bioaccessibility method was judged to be inappropriate for the surface wipe samples. The blank media bioaccessible Pb values were similar to the values observed in the field samples. Given the relatively small amount of dust collected on the wipe, as compared with the large mass of wipe material, and the relatively low amounts of Pb measured, it is likely that any calculated bioaccessibility attributed to the dust likely is to be impacted significantly by the background levels in the sampling and analysis procedures. Gaining a clear understanding of this observation requires additional research.

6.10.2 Lessons Learned with Regard to Bioaccessibility Data

An objective of this scoping study was to apply existing wipe collection and material analytical procedures developed for soil media and to assess their performance. A few of the lessons learned are described below.

- Sufficient quantities of samples are needed to meet extraction requirements for EPA SOP 9200.1-86; this should be considered in sampling designs.
- Limitations on cutting samples prevented further homogenization of samples.
- Better method detection limits (MDLs) for the in vitro extractions were achieved relative to the EPA SOP 9200.1-86 requirements and values previously published.
- Additional methods development and validation research is recommended before this wipe method is applied in future studies.

6.11 Methods Evaluation Summary

A summary evaluation of the sample collection and analysis methods for the several types of samples collected in this scoping study is provided in Table 9.

Table 9. Overall Summary and Assessment of Methods Applied in This Scoping Study

Sample Type	Sample Collection	Sample Analysis	Other Comments
Air VOCs	• Grab samples simple to collect. • Short time needed. • Can be collected directly over field or playground.	• Standard Method TO-15 (GC/MS) provided data for 56 analytes with good precision and accuracy. • Sensitivity was sufficient to measure analytes in ambient air.	• Overall, this method was simple to implement and provided adequate data.
Air PM_{10} (mass, metals, SEM)	• Large amount of equipment needed. • Technical expertise required. • Required 8-10 h of time to collect. • Could not always be placed directly on field because of activity.	• Standard research methods provided data for mass concentration and for multiple metals. • Sensitivity sufficient to measure analytes in ambient air. • Precision and accuracy were good.	• Overall, this method was somewhat complex and time consuming to implement and provided adequate data. • Identification of tire crumb particles was difficult because of lack of standard morphology or composition.
Surface Wipes (turf fields)	• Moderately simple to collect. • Short time needed. • Method not validated for synthetic turf surfaces. • Wipes can collect infill particles and turf blades (that were removed for these analyses).	• Standard EPA Methods 3050B and 6020 applied with good recovery and analytical precision. • Sensitivity was very good and sufficient to measure low levels of multiple metals. • EPA Pb in vitro bioaccessibility method 9200.1-86 found not to be appropriate for wipe samples.	• Overall, this method was relatively simple to implement. • The method provided quantitative measurement results, but the method has not been validated for use on synthetic turf field surfaces. • The in vitro Pb bioaccessibility method was judged to be inappropriate for the surface wipe samples.
Tire Crumb Infill (turf fields)	• Simple to collect. • Short time needed. • Decisions needed on area and depth of material collection.	• Standard EPA Methods 3050B and 6020 applied with good analytical precision. • EPA Pb in vitro bioaccessibility method 9200.1-86 applied with good analytical precision. • Nonhomogeneous material made assessment of analyte recoveries difficult. • Sensitivity was very good and sufficient to measure low levels of multiple metals.	• Overall, this method was relatively simple to implement. • The method provided quantitative measurement results, but the method has not been validated for use on tire crumb particles. • Improved quality control methods and materials required to assess metal recoveries. • Nonhomogeneity of Pb has implications for site sampling, analysis, and data interpretation.

Table 9. Overall Summary and Assessment of Methods Applied in This Scoping Study (cont'd.)

Sample Type	Sample Collection	Sample Analysis	Other Comments
Blades (turf fields)	• Simple to collect. • Relatively short time needed. • Limited in this study to collecting loose blades where available. • Larger sample size needed for analysis (>1 g each) than were collected for some samples in this study. • Collection of different colors revealed different Pb levels at some fields; this should be considered in site sampling plans.	• Standard EPA Methods 3050B and 6020 applied with good analytical precision. • EPA Pb in vitro bioaccessibility method 9200.1-86 applied with good analytical precision. • Nonhomogeneous material made assessment of analyte recoveries difficult. • Sensitivity was very good and sufficient to measure low levels of multiple metals of interest.	• Overall, this method was relatively simple to implement. • The method provided quantitative measurement results, but the method has not been validated for use on synthetic turf blades. • Improved quality control methods and materials required to assess metal recoveries. • Differences for Pb depending on blade color have implications for site sampling and analysis.
Tire Crumb Rubber (playgrounds)	• Simple to collect. • Short time needed. • Decisions required on site sampling plan with regard to location and number of areas and depth of material for collection.	• Standard EPA Methods 3050B and 6020 applied with good analytical precision. • EPA Pb in vitro bioaccessibility method 9200.1-86 applied with good analytical precision. • Sensitivity was very good and sufficient to measure low levels of multiple metals of interest. • Nonhomogeneous material made assessment of analyte recoveries difficult. • Tire crumb pieces were larger than the 1 g desired for analysis; homogenization and subsampling may be needed in future work.	• Overall, sample collection was simple to implement, but analysis was more difficult because of sample size issues. • The method provided quantitative measurement results, but the method has not been validated for use on tire crumb particles. • Improved quality control methods and materials required to assess metal recoveries. • Nonhomogeneity of Pb has implications for site sampling, analysis, and data interpretation.

7. References

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Appendix A

List of Sample Collection and Analysis Methods

NOTE: The following methods have not been evaluated for collecting and analyzing samples from synthetic turf fields or from playgrounds with tire crumb rubber.

Research Operating Procedure for the Collection of Particulate Matter (PM) Air Samples at Playgrounds and Synthetic Turf Fields

Research Operating Procedure for the Collection of Tire Crumb Material at Playgrounds

Research Operating Procedure for the Collection of “Grass Blade” Fibers from Synthetic Turf Fields

Research Operating Procedure for the Collection of Infill Material from Synthetic Turf Fields

Research Operating Procedure for the Collection of Volatile Organic Chemicals in Air Using Canisters

ASTM E1792-03: Standard Specification for Wipe Sampling Materials for Lead in Surface Dust

ASTM E1728-03: Standard Practice for Collection of Settled Dust Samples Using Wipe Sampling Methods for Subsequent Lead Determination

Recommended Operating Procedure for Elemental Analysis of Particulate Matter on Membrane Filters by the LBL XRF Spectrometer

Standard Operating Procedure for the Gravimetric Determination of Particle Mass on Teflon Air Sampling Filters

Standard Operating Procedures for the USEPA-NERL Scanning Electron Microscopy/ Energy-Dispersive X-Ray Analysis (SEM/EDX) Laboratory

Compendium Method TO-15: Determination of Volatile Organic Compounds (VOCs) in Air Collected in Specially-Prepared Canisters and Analyzed by Gas Chromatography/Mass Spectrometry (GC/MS); (Region 1 EIASOP-AIRCAN9: “Standard Operating Procedure for the Analysis of Volatile Organic Compounds in Air by Gas Chromatography/Ion Trap Detector)”

EPA SW-846 Method 3050B: Acid Digestion of Sediments, Sludges, and Soils. Revision 2. December 1996

EPA SW-846 Method 6020A: Inductively Coupled Plasma-Mass Spectrometry. Revision 1. February 2007

EPA 9200.1-86. Standard Operating Procedure for an In Vitro Bioaccessibility Assay for Lead in Soil. May 2008

Appendix B

Quality Control and Quality Assurance Results

Table B-1. Field and Laboratory Blank Measurement Results for Volatile Organic Compounds in Air

Table B-2. Percent Recovery of Air Volatile Organic Compounds in Field and Laboratory Controls

Table B-3. Relative Percent Difference in Measurement Results for Air Volatile Organic Compounds in Field Duplicate Canister Samples and in Repeat Analysis of Canister Samples in the Laboratory

Table B-4. ICP/MS Operating Parameter Settings

Table B-5. ICP/MS Isotopes and Interference Corrections

Table B-6. Concentrations of Individual Metals in Working Calibration Standards

Table B-7. ICP/MS Method Detection Limits

Table B-8. Summary of ICP/MS QC Criteria

Table B-9. Summary of ICP/MS Instrumental QC Results

Table B-10. Recovery of Metals Spiked in Extraction Reagent Blank

Table B-11. Recovery of Metals-Spiked Solution on Matrix of Interest

Table B-12. Total Extractable Recoveries for NIST SRM 2710 Spiked into Extraction Solution

Table B-13. Total Extractable Recoveries for NIST SRM 2710 Spiked onto Ghost Wipe Media

Table B-14. Bottle Blank Data Used for Sample Correction and Reagent Blank Data Method 3050B

Table B-15. Laboratory and Field Ghost Wipe Blank Samples

Table B-16. Relative Percent Differences for the Analysis of Duplicate Aliquots of Tire Crumb Infill from Synthetic Fields and Playground Tire Crumb Samples

Table B-17. Recommended Control Limits for In Vitro Soil Quality Control Samples According to EPA Method 9200.1-86

Table B-18. Summary Control Limit Results for In Vitro Pb Bioaccessibility Quality Control Samples

Table B-19. Percent Recovery Results for In Vitro Blank Spikes

Table B-20. Summary of Pb In Vitro Extractable Values for NIST SRM 2710

Table B-21. Summary of Pb In Vitro Extractable Values for NIST SRM 2710 Spiked onto Ghost Wipe Media

Table B-22. Results for In Vitro Pb Solution Spikes onto Blank Ghost Wipes and Tire Crumb Samples

Table B-23. In Vitro Pb Bioaccessibility Extraction Duplicates for Synthetic Turf Field Tire Crumb Infill

Table B-24. In Vitro Pb Bioaccessibility Extraction Duplicates for Playground Tire Crumb

Table B-1. Field and Laboratory Blank Measurement Results (ppbV) for Volatile Organic Compounds (VOCs) in Air

VOC	Field Blank MDL	Sample MDL	Field Blanks			Laboratory Blanks				
			P1	F4	F1D1	P1	F2	F4	F1D1	F1D2
1,1,1-Trichloroethane	0.05	0.076[a]	ND[b]	ND	ND	ND	ND	ND	ND	ND
1,1,2,2-Tetrachloroethane	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
1,1,2-Trichloroethane	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
1,1-Dichloroethane	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
1,1-Dichloroethylene	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
1,2,4-Trichlorobenzene	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
1,2,4-Trimethylbenzene	0.05	0.076[a]	ND	ND	0.360	ND	ND	ND	ND	ND
1,2-Dibromoethane	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
1,2-Dichlorobenzene	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
1,2-Dichloroethane	0.05	0.076[a]	ND	ND	0.073	ND	ND	ND	ND	ND
1,2-Dichloropropane	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
1,3,5-Trimethylbenzene	0.05	0.076[a]	ND	ND	0.120	ND	ND	ND	ND	ND
1,3-Butadiene	0.10	0.15[c]	ND	ND	0.250	ND	ND	ND	ND	ND
1,3-Dichlorobenzene	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
1,4-Dichlorobenzene	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
2-Hexanone	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
4-Ethyltoluene	0.05	0.076[a]	ND	ND	0.380	ND	ND	ND	ND	ND
Acrylonitrile	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
Allyl Chloride	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
Benzene	0.05	0.076[a]	ND	ND	1.11	ND	ND	ND	ND	ND
Benzylchloride	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
Bromodichloromethane	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
Bromoform	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
c-1,2-Dichloroethylene	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
c-1,3-Dichloropropylene	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
Carbon Tetrachloride	0.05	0.076[a]	ND	ND	0.040	ND	ND	ND	ND	ND
Chlorobenzene	0.05	0.076[a]	ND	ND	0.510	ND	ND	ND	ND	ND
Chloroethane	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
Chloroform	0.05	0.076[a]	ND	ND	0.049	ND	ND	ND	ND	ND
Cyclohexane	0.05	0.076[a]	ND	ND	12.0	ND	ND	ND	ND	ND
Dibromochloromethane	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
Dichlorodifluoromethane	0.05	0.076[a]	ND	ND	0.270	ND	ND	ND	ND	ND
Dichlorotetrafluoroethane	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
Ethylbenzene	0.05	0.076[a]	ND	ND	1.63	ND	ND	ND	ND	ND
Heptane	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
Hexachloro-1,3-butadiene	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
Hexane	0.05	0.076[a]	ND	ND	6.20	ND	ND	ND	ND	ND
m&p-Xylenes	0.10	0.15[c]	ND	ND	4.27	ND	ND	ND	ND	ND
Methyl Ethyl Ketone	0.05	0.076[a]	0.100	0.059	3.83	0.040	0.044	ND	ND	ND

Table B-1. Field and Laboratory Blank Measurement Results (ppbV) for Volatile Organic Compounds (VOCs) in Air (cont'd.)

VOC	Field Blank MDL	Sample MDL	Field Blanks			Laboratory Blanks				
			P1	F4	F1D1	P1	F2	F4	F1D1	F1D2
Methyl Isobutyl Ketone	0.05	0.076[a]	ND	ND	0.190	ND	ND	ND	ND	ND
Methylbromide	0.05	0.076[a]	ND	ND	0.042	ND	ND	ND	ND	ND
Methylchloride	0.05	0.076[a]	ND	ND	0.440	ND	ND	ND	ND	ND
Methylene Chloride	0.05	0.076[a]	ND	ND	0.400	ND	ND	ND	ND	ND
Methyl-t-butyl ether	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
o-Xylene	0.05	0.076[a]	ND	ND	1.35	ND	ND	ND	ND	ND
Styrene	0.05	0.076[a]	ND	ND	1.10	ND	ND	ND	ND	ND
t-1,2-Dichloroethylene	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
t-1,3-Dichloropropylene	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
Tetrachloroethylene	0.05	0.076[a]	ND	ND	0.160	ND	ND	ND	ND	ND
Tetrahydrofuran	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
Toluene	0.05	0.076[a]	ND	ND	29.0	ND	ND	ND	ND	ND
Trichloroethylene	0.05	0.076[a]	ND	ND	0.180	ND	ND	ND	ND	ND
Trichlorofluoromethane	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
Trichlorotrifluoroethane	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
Vinyl Bromide	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND
Vinylchloride	0.05	0.076[a]	ND	ND	ND	ND	ND	ND	ND	ND

[a] Range from 0.070 to 0.079 ppbV.
[b] ND = not detected.
[c] Range from 0.14 to 0.16 ppbV.

Table B-2. Percent Recovery[a] of Air Volatile Organic Compounds (VOCs) in Field and Laboratory Controls

VOC	Spiking Level (ppbV)	Field Controls					Laboratory Controls				
		P1	F4	F1D1	Mean	Std. Dev.	P1	F4	F1D2	Mean	Std. Dev.
1,1,1-Trichloroethane	4.83	124	114	136	125	10.8	120	125	128	124	4.3
1,1,2,2-Tetrachloroethane	4.99	98	86	99	94	7.5	93	93	93	93	0.1
1,1,2-Trichloroethane	4.82	112	104	119	112	7.8	108	110	109	109	1.1
1,1-Dichloroethane	4.90	112	99	108	106	6.8	106	99	93	99	6.2
1,1-Dichloroethylene	4.78	103	97	122	108	12.8	106	101	109	105	3.9
1,2,4-Trichlorobenzene	4.09	72	44	70	62	15.7	69	61	70	66	5.0
1,2,4-Trimethylbenzene	5.04	101	84	102	96	10.1	96	98	96	97	1.2
1,2-Dichlorobenzene	4.97	91	77	91	86	8.4	88	85	86	86	1.7
1,2-Dichloropropane	4.85	112	105	119	112	6.7	102	114	109	108	5.8
1,3,5-Trimethylbenzene	4.87	111	97	112	107	8.8	111	108	109	109	1.3
1,3-Dichlorobenzene	5.00	92	77	92	87	8.5	89	83	86	86	2.9
Benzene	4.83	116	105	120	114	7.7	114	118	111	114	3.5
c-1,2-Dichloroethylene	4.80	107	97	113	106	8.1	106	99	99	101	3.9
Carbon Tetrachloride	4.84	101	26	132	87	55.0	76	107	120	101	22.7
Chlorobenzene	4.86	103	97	105	101	4.4	102	102	104	102	1.3
Chloroethane	4.81	96	66	112	91	23.2	90	101	91	94	6.1
Chloroform	4.90	110	99	106	105	5.8	103	104	96	101	4.6
Dichlorodifluoromethane	4.05	113	95	107	105	9.0	97	95	101	98	3.0
Dichlorotetrafluoroethane	3.84	103	96	109	103	6.6	100	104	99	101	2.5
Ethylbenzene	4.88	79	94	109	94	15.0	84	104	105	97	12.0
Hexachloro-1,3-butadiene	4.41	92	72	89	84	10.7	90	81	103	91	11.1
m&p-Xylenes	4.97	106	95	111	104	8.3	106	108	106	107	1.0
Methylchloride	4.38	90	103	98	97	6.5	89	87	82	86	3.8
Methylene Chloride	4.91	111	101	114	108	6.7	105	105	101	104	2.4
o-Xylene	4.60	108	93	111	104	9.7	102	105	104	104	1.2
Tetrachloroethylene	4.86	109	100	108	106	5.0	101	107	105	104	3.0
Toluene	4.83	107	101	115	108	7.1	107	108	108	108	0.3
Trichloroethylene	4.92	113	103	112	109	5.3	98	107	109	105	5.5
Trichlorofluoromethane	4.76	117	106	120	114	7.3	114	116	110	113	3.1
Vinylchloride	3.09	104	97	116	106	9.2	103	105	102	103	1.4

[a] $\left| \frac{\text{Found}}{\text{Expected}} \right| * 100$

Table B-3. Relative Percent Difference (RPD)[a] in Measurement Results for Air Volatile Organic Compounds (VOCs) in Field Duplicate Canister Samples and in Repeat Analysis of Canister Samples in the Laboratory

	Field Duplicates					Laboratory Repeat Analysis				
VOC	RPD P1	RPD F4	RPD F1D1	Mean RPD	Std. Dev RPD	RPD P1	RPD F4	RPD F1D1	Mean RPD	Std. Dev. RPD
Benzene	4.8	13.3	9.5	9.2	4.3	12.8	0.0	7.9	6.9	6.4
Carbon Tetrachloride	9.3	3.4	8.3	7.0	3.1	12.4	1.1	1.0	4.9	6.6
Dichlorodifluoromethane	3.8	0.0	7.7	3.8	3.8	1.9	4.1	5.6	3.9	1.9
Hexane	44.9	28.6	105.5	59.7	40.5	—	0.0	31.2	15.6	22.1
m&p-Xylenes	—	2.6	74.2	38.4	50.6	—	8.7	3.7	6.2	3.5
Methyl Ethyl Ketone	11.8	4.8	28.6	15.0	12.2	0.0	2.0	14.6	5.6	7.9
Methyl Isobutyl Ketone	—	—	21.1	21.1		—	—	—		
Methylchloride	8.5	2.1	4.1	4.9	3.3	0.0	0.0	8.7	2.9	5.0
Methylene Chloride	44.4	20.3	—	32.4	17.0	4.3	8.7	12.0	8.3	3.8
Toluene	107.1	6.5	143.9	85.8	71.1	6.9	5.4	30.8	14.4	14.2
Trichlorofluoromethane	0.0	0.0	11.3	3.8	6.5	0.0	0.0	11.3	3.8	6.5
Trichlorotrifluoroethane	2.7	1.4	1.2	1.8	0.8	2.7	2.8	7.7	4.4	2.8

[a]100 * ABS(M1- M2) / [(M1+M2) / 2}

Table B-4. ICP/MS Operating Parameter Settings

Instrument Settings			
RF Power	1,200-1,260 W		
Ar Gas Flow Rates:			
Cool	13 Lpm		
Auxiliary	0.9-1.0 Lpm		
CCT Gas Flow (He 93%/ H 7%)	~10 µL/min		
Sampler Cone (Ni/Cu)	1.1-mm diameter orifice sample cone		
Skimmer Cone (Ni/Cu)	0.75-mm diameter skimmer cone		
Nebulizer	Concentric nebulizer, 35 PSI, 1 mL/min		
Spray Chamber	Air-cooled cyclone		
Detector Dead Time	55 ns		
Internal Standard Solution	40-200 ppb solution of 6 Li 45 Sc 89 Y In115 and 159Tb		
Acquisition Parameters (Normal Mode)			
Major	**Minor**	**Global**	**Add. Gases**
Extraction	Lens	Standard resolution	CCT – 0
Lens 1	Forward power 1,400	High resolution	
Lens 2	Horizontal	Analogue detector	
Focus	Vertical	PC detector	
D1	DA		
D2 -140	Cool		
Pole Bias 0	Auxiliary		
Hexapole Bias -4.0	Sampling depth 130-140		
Acquisition Parameters (Collision Cell Technology [CCT] Mode)			
Major	**Minor**	**Global**	**Add. Gases**
Extraction	Lens	Standard resolution	CCT – ~10 µL/min
Lens 1	Forward power 1,400	High resolution	
Lens 2	Horizontal	Analogue detector	
Focus	Vertical	PC detector	
D1	DA		
D2 -140	Cool		
Pole Bias -17.0	Auxiliary		
Hexapole Bias -20.0	Sampling depth 130-140		
Operating Parameters			
Standard Resolution	0.75 ± 0.1 amu		
High Resolution	0.30 ± 0.1 amu		
Integration Type	Average		
Calibration Type	Linear		
Number of scans per replicate	1		
Number of replicates (runs)	3-7		

Table B-5. ICP/MS Isotopes and Interference Corrections

Analyte	Mass	Interference
Pb	207	
Pb	208	
Cr	52	
Zn	66	
Al	27	
As	75	
Ba	137	
Cd	111	

Analyte	Mass	Interference
Cd	114	-0.027 * 118 Sn
Cu	65	
Fe	54	-0.028 * 52 Cr
Fe	56	-0.15 * 43 Ca
Mn	55	
Ni	60	-0.002 * 34 Ca
Ni	62	

Table B-6. Concentrations of Individual Metals in Working Calibration Standards

Metal	LoCal1 (ppb)	LoCal2 (ppb)	HiCal1 (ppm)	HiCal2 (ppm)	LLQC CRI (ppb)	LoCal3 (ppb)	LoCal2 1:100 (ppb)
Pb	250	500			1	1,000	5
Cr	250	500			2	1,000	5
Zn	250	500			2	1,000	5
Al	250	500			30	1,000	5
As	250	500			1	1,000	5
Ba	250	500			10	1,000	5
Cd	250	500			1	1,000	5
Cu	250	500			2	1,000	5
Fe	250	500	50	100		1,000	5
Mn	250	500			1	1,000	5
Ni	250	500			1	1,000	5
Internal Standards							
Li	200						
Sc	200						
Y	40						
In	40						
Tb	40						

Table B-7. ICP/MS Method Detection Limits (ppb)[a]

Metal	Isotope	In Vitro Method	EPA Method 3050B
Pb	208	0.082	0.092
Cr	52	0.201	0.175
Zn	66	0.409	0.388
Al	27	1.99	2.47
As	75	0.366	0.246
Ba	137	0.668	0.634
Cd	111	0.219	0.224
Cu	65	0.335	0.350
Fe	56	6.4	4.3
Mn	55	0.178	0.144
Ni	60	0.268	0.332

[a]Calculated by formula in 40 CRF Part 136. MDLs reported here are for sample extracts delivered to the instrument.
For In vitro matrix: First CRI chosen per day over 6 analysis days plus 1 extra. (Note: One metal (Fe) not spiked into CRI so concentration at reagent blank level.
For EPA 3050B matrix: One CRI chosen per day over 7 analysis days.

Table B-8. Summary of ICP/MS QC Criteria[a]

Name	Acceptance Criteria	Minimum Value Requirement
Initial Calibration Verification	90%-110%	
Initial Calibration Blank	<CRQL[b]	
Continuing Calibration Verification	90%-110%	
Continuing Calibration Blank	<CRQL	
Interference Check Solution A	±3CRQL or ±20% true value	
Interference Check Solution AB	±3CRQL or ±20% true value	
Contract Required Quantitation Limit Check	±30%, except ±50% for Co, Mn, Zn	
Duplicate Samples Relative Percent Difference	<20%	50 times CRQL
Serial Dilution Samples Percent Difference	<10%	50 times CRQL
Post Digestion Spike Samples	75%-125%	
Sample Extract QC		
Spike	75%-125%	
SRM	75%-125%	

[a]Based on EPA Method 6020A QC criteria.
[b]CRQL = contract required quantitation limit.

Table B-9. Summary of ICP/MS Instrumental QC Results

In EPA 3050B 5% HNO_3 Matrix, n=4				
Metal	**Mass (amu)**	**DUP[a] Criteria**	**DUP RPD[b] Found**	**Status (pass/fail)**
Pb	208	<20%	0.117%-7.83%	P
Cr	52	<20%	0.145%-3.54%	P
Zn	66	<20%	0.081%-1.26%	P
Al	27	<20%	0.023%-5.26%	P
As	75	<20%	0.929%-12.8%	P
Ba	137	<20%	0.563%-1.41%	P
Cd	111	<20%	1.048%-1.26%	P
Cu	65	<20%	0.011%-1.40%	P
Fe	56	<20%	0.110%-2.37%	P
Mn	55	<20%	1.09%-3.61%	P
Ni	60	<20%	0.478%-2.50%	P
Metal	**Mass (amu)**	**SER[c] Criteria**	**SER Difference**	**Status (pass/fail)**
Pb	208	<10%	2.54%-7.24%	P
Cr	52	<10%	0.167%	P
Zn	66	<10%	2.41%-7.74%, 14.8%	F
Al	27	<10%	1.50%-4.31%	P
As	75	<10%	*[d]	N/A
Ba	137	<10%	0.938%-4.99%	P
Cd	111	<10%	*	N/A
Cu	65	<10%	2.34%-5.72%	P
Fe	56	<10%	*	N/A
Mn	55	<10%	*	N/A
Ni	60	<10%	3.43%	P
Metal	**Mass (amu)**	**PDS[e] Criteira**	**PDS Recovery**	**Status (pass/fail)**
Pb	208	75%-125%	100%-104%	P
Cr	52	75%-125%	86.7%-89.0%	P
Zn	66	75%-125%	99.6%-109%	P
Al	27	75%-125%	*	N/A
As	75	75%-125%	98.7%-105%	P
Ba	137	75%-125%	77.2%-100%	P
Cd	111	75%-125%	94.6%-103%	P
Cu	65	75%-125%	96.5%-101%	P
Fe	56	75%-125%	*	N/A
Mn	55	75%-125%	*	N/A
Ni	60	75%-125%	92.8%-99.2%	P

Table B-9. Summary of ICP/MS Instrumental QC Results (cont'd.)

In In Vitro 2% HNO_3 Matrix, n=5				
Metal	**Mass (amu)**	**DUP Criteria**	**DUP RPD Found**	**Status (pass/fail)**
Pb	208	<20%	0.684%-4.70%	P
Cr	52	<20%	*	N/A
Zn	66	<20%	0.104%-1.98%	P
Al	27	<20%	1.90%-11.0%	P
As	75	<20%	*	N/A
Ba	137	<20%	0.142%-2.38%	P
Cd	111	<20%	*	N/A
Cu	65	<20%	0.142%-9.38%	P
Fe	56	<20%	*	N/A
Mn	55	<20%	*	N/A
Ni	60	<20%	*	N/A
Metal	**Mass (amu)**	**SER Criteria**	**SER Difference**	**Status (pass/fail)**
Pb	208	<10%	0.062%	P
Cr	52	<10%	*	N/A
Zn	66	<10%	0.169%-9.40%	P
Al	27	<10%	8.49%, 26.0%	F
As	75	<10%	*	N/A
Ba	137	<10%	0.045%-2.51%	P
Cd	111	<10%	*	N/A
Cu	65	<10%	*	N/A
Fe	56	<10%	*	N/A
Mn	55	<10%	*	N/A
Ni	60	<10%	*	N/A
Metal	**Mass (amu)**	**PDS Criteria**	**PDS Recovery**	**Status (pass/fail)**
Pb	208	75%-125%	94.7%-106%	P
Cr	52	75%-125%	91.2%-102%	P
Zn	66	75%-125%	95.4%-110%	P
Al	27	75%-125%	*	N/A
As	75	75%-125%	90.0%-103%	P
Ba	137	75%-125%	88.0%-108%	P
Cd	111	75%-125%	97.3%-107%	P
Cu	65	75%-125%	91.2%-111%	P
Fe	56	75%-125%	*	N/A
Mn	55	75%-125%	*	N/A
Ni	60	75%-125%	97.2%-108%	P

[a]DUP = duplicate aliquot of extract analyzed independently.
[b]RPD = relative percent difference.
[c]SER = serial dilution of extract.
[d]Concentrations too low to meet QC criteria.
[e]PDS = postdigestion spike.

Table B-10. Recovery of Metals Spiked in Extraction Reagent Blank

Sample ID	Description	Spiked Amount (total ug spiked)	Net Total Extractable (total ug found)	Percent Recovery
Primary Metals of Interest				
Cr				
TC1-2	Blank Spike	640	600	93.7
TC2-2	Blank Spike	640	616	96.3
TC3-2	Blank Spike	2,500	2,340	93.8
TC4-2	Blank Spike	2,500	2,350	94.1
TC5-2	Blank Spike	2,500	2,320	92.7
TC6-2	Blank Spike	2,500	2,390	95.8
TC7-2	Blank Spike	2,500	2,370	94.8
TC8-2	Blank Spike	2,500	2,380	95.0
X (n=8)				94.5
Pb				
TC1-2	Blank Spike	1,000	949	94.9
TC2-2	Blank Spike	1,000	1,070	107
TC3-2	Blank Spike	1,000	987	98.7
TC4-2	Blank Spike	1,000	985	98.5
TC5-2	Blank Spike	1,000	980	98.0
TC6-2	Blank Spike	1,000	974	97.4
TC7-2	Blank Spike	1,000	999	99.9
TC8-2	Blank Spike	1,000	1,000	100
X (n=8)				99.3
Zn				
TC1-2	Blank Spike	800	774	96.8
TC2-2	Blank Spike	800	747	93.4
TC3-2	Blank Spike	2,500	2,390	95.7
TC4-2	Blank Spike	2,500	2,390	95.5
TC5-2	Blank Spike	2,500	2,370	94.8
TC6-2	Blank Spike	2,500	2,420	96.7
TC7-2	Blank Spike	2,500	2,400	95.9
TC8-2	Blank Spike	2,500	2,400	96.1
X (n=8)				95.6
Secondary Metals of Interest				
Al				
TC1-2	Blank Spike	0	5.40	Not spiked
TC2-2	Blank Spike	0	31.4	Not spiked
TC3-2	Blank Spike	0.2	44.2	Not spiked
TC4-2	Blank Spike	0.2	38.3	Not spiked
TC5-2	Blank Spike	0.2	36.7	Not spiked
TC6-2	Blank Spike	0.2	29.3	Not spiked
TC7-2	Blank Spike	0.2	32.9	Not spiked
TC8-2	Blank Spike	0.2	20.6	Not spiked
X				Not spiked
As				
TC1-2	Blank Spike	0	23.1	Not spiked
TC2-2	Blank Spike	0	22.9	Not spiked
TC3-2	Blank Spike	500	449	89.8
TC4-2	Blank Spike	500	459	91.8
TC5-2	Blank Spike	500	449	89.8
TC6-2	Blank Spike	500	423	84.5
TC7-2	Blank Spike	500	453	90.6
TC8-2	Blank Spike	500	463	92.5
X (n=6)				89.8

Table B-10. Recovery of Metals Spiked in Extraction Reagent Blank (cont'd.)

Sample ID	Description	Spiked Amount (total µg spiked)	Net Total Extractable (total µg found)	Percent Recovery
Ba				
TC1-2	Blank Spike	0	2.97	Not spiked
TC2-2	Blank Spike	0	4.58	Not spiked
TC3-2	Blank Spike	2,510	2,420	96.6
TC4-2	Blank Spike	2,510	2,460	98.1
TC5-2	Blank Spike	2,510	2,420	96.3
TC6-2	Blank Spike	2,510	2,480	98.6
TC7-2	Blank Spike	2,510	2,490	99.2
TC8-2	Blank Spike	2,510	2,490	99.1
X (n=6)				98.0
Cd				
TC1-2	Blank Spike	160	157	98.0
TC2-2	Blank Spike	160	150	93.6
TC3-2	Blank Spike	497	475	95.6
TC4-2	Blank Spike	497	480	96.6
TC5-2	Blank Spike	497	465	93.5
TC6-2	Blank Spike	497	483	97.3
TC7-2	Blank Spike	497	480	96.6
TC8-2	Blank Spike	497	480	96.5
X (n=8)				96.0
Cu				
TC1-2	Blank Spike	800	793	99.1
TC2-2	Blank Spike	800	800	100
TC3-2	Blank Spike	2,540	2,410	95.0
TC4-2	Blank Spike	2,540	2,410	95.0
TC5-2	Blank Spike	2,540	2,400	94.6
TC6-2	Blank Spike	2,540	2,450	96.3
TC7-2	Blank Spike	2,540	2,420	95.4
TC8-2	Blank Spike	2,540	2,430	95.5
X (n=8)				96.4
Fe				
TC1-2	Blank Spike	0	0	Not spiked
TC2-2	Blank Spike	0	27.7	Not spiked
TC3-2	Blank Spike	0	3.00	Not spiked
TC4-2	Blank Spike	0	0.222	Not spiked
TC5-2	Blank Spike	0	2.12	Not spiked
TC6-2	Blank Spike	0	0.213	Not spiked
TC7-2	Blank Spike	0	0.668	Not spiked
TC8-2	Blank Spike	0	0.219	Not spiked
X				Not spiked
Mn				
TC1-2	Blank Spike	400	377	94.2
TC-2-2	Blank Spike	400	386	96.4
TC3-2	Blank Spike	0.02	0.311	Not spiked
TC4-2	Blank Spike	0.02	0.004	Not spiked
TC5-2	Blank Spike	0.02	0.028	Not spiked
TC6-2	Blank Spike	0.02	0	Not spiked
TC7-2	Blank Spike	0.02	0.010	Not spiked
TC8-2	Blank Spike	0.02	0.121	Not spiked
X (n=2)				95.3

Table B-10. Recovery of Metals Spiked in Extraction Reagent Blank (cont'd.)

Sample ID	Description	Spiked Amount (total µg spiked)	Net Total Extractable (total µg found)	Percent Recovery
Ni				
TC1-2	Blank Spike	0	0.869	Not spiked
TC-2-2	Blank Spike	0	0.312	Not spiked
TC3-2	Blank Spike	1,250	1,220	97.2
TC4-2	Blank Spike	1,250	1,220	97.7
TC5-2	Blank Spike	1,250	1,200	95.8
TC6-2	Blank Spike	1,250	1,240	99.2
TC7-2	Blank Spike	1,250	1,220	97.5
TC8-2	Blank Spike	1,250	1,230	98.3
X (n=6)				97.6

Table B-11. Recovery of Metals-Spiked Solution on Matrix of Interest

Media and Sample	Spiked Amount (µg)	Net Spiked Total Extractable (µg)	Net Media Total Extractable (µg)	Media Corrected Spike (µg)	Percent Recovery
Pb on Wipes					
Blank Ghost Wipe			0.227		
Wipe with Spike	1,000	921		920	92.0
Blank Ghost Wipe			0.694		
Wipe with Spike	991	994		993	100
Blank Ghost Wipe			1.08		
Wipe with Spike	991	995		994	100
Mean					99.4
Pb on Infill					
F4-L1-S1-A1			41.1		
F4-L1-S1-A1	1,000	974		933	93.3
F4-L1-D1-A1			24.8		
F4-L1-D1-A1	1,000	214		190	19.0
F1-L3-S1-A1			20.6		
F1-L3-S1-A1	991	854		834	84.1
F2-L2-D1-A1			36.4		
F2-L2-D1-A1	991	889		853	86.0
Pb on Crumb					
P1-LA-TC1			0.989		
P1-LA-TC1	1,000	317		316	31.6
P1-LA-TC2			6.31		
P1-LA-TC2	991	233		227	22.9
P1-LB-TC1			443		
P1-LB-TC1	991	276		-167	N/A
Cr on Wipes					
Blank Ghost Wipe			0.091		
Wipe with Spike	640	580		580	90.7
Blank Ghost Wipe			6.24		
Wipe with Spike	2,490	2,400		2,390	96.1
Blank Ghost Wipe			13.0		
Wipe with Spike	2,490	2,370		2,360	94.8
Mean					93.9
Cr on Infill					
F4-L1-S1-A1			0.602		
F4-L1-S1-A1	640	596		595	93.0
F4-L1-D1-A1			0.352		
F4-L1-D1-A1	640	106		106	16.6
F1-L3-S1-A1			0.544		
F1-L3-S1-A1	2,490	2,160		2,160	86.7

Table B-11. Recovery of Metals-Spiked Solution on Matrix of Interest (cont'd.)

Media and Sample	Spiked Amount (µg)	Net Spiked Total Extractable (µg)	Net Media Total Extractable (µg)	Media Corrected Spike (µg)	Percent Recovery
F2-L2-D1-A1			0.018		
F2-L2-D1-A1	2,490	2,080		2,080	83.6
Mean					69.9
Cr on Crumb					
P1-LA-TC1			0.281		
P1-LA-TC1	640	115		115	17.9
P1-LA-TC2			0.721		
P1-LA-TC2	2,490	598		598	24.0
P1-LB-TC1			0.761		
P1-LB-TC1	2,490	788		787	31.6
Mean					24.4
Zn on Wipes					
Blank Ghost Wipe			4.06		
Wipe with Spike	800	763		759	94.8
Blank Ghost Wipe			13.0		
Wipe with Spike	2,490	2,420		2,400	96.5
Blank Ghost Wipe			23.6		
Wipe with Spike	2,490	2,430		2,410	96.7
Mean					96.0
Zn on Infill					
F4-L1-S1-A1			9,940		
F4-L1-S1-A1	800	8,960		-989	N/A
F4-L1-D1-A1			4,880		
F4-L1-D1-A1	800	6,040		1,159	1,459
F1-L3-S1-A1			7,930		
F1-L3-S1-A1	2,490	21,700		13,800	555
F2-L2-D1-A1			10,300		
F2-L2-D1-A1	2,490	11,700		1,420	56.8
Mean					251
Zn on Crumb					
P1-LA-TC1			4,330		
P1-LA-TC1	800	5,270		940	117.5
P1-LA-TC2			6,730		
P1-LA-TC2	2,490	13,100		6,380	256
P1-LB-TC1			17,500		
P1-LB-TC1	2,490	14,000		-3,430	N/A
Mean					186

Table B-12. Total Extractable Recoveries for NIST SRM 2710 Spiked into Extraction Solution

Metal	Batch	SRM Certified Concentration (ug/g)	Found Concentration (ug/g)	Percent Recovery	SRM Percent Leachable Recovery
As	1	626	535	85.5	94
	2	626	502	80.3	94
	3	626	514	82.0	94
	4	626	492	78.5	94
	6	626	502	80.2	94
	8	626	498	79.5	94
Mean				81.0	
Cr[a]	1	39	14.2	36.3	49
	2	39	16.3	41.8	49
	3	39	15.1	38.6	49
	4	39	10.1	26.0	49
	6	39	14.8	38.0	49
	8	39	13.8	35.4	49
Mean				37.5	
Pb	1	5,530	5,100	92.2	92
	2	5,530	4,740	85.7	92
	3	5,530	4,830	87.4	92
	4	5,530	4,830	87.3	92
	6	5,530	4,740	85.6	92
	8	5,530	4,630	83.7	92
Mean				87.0	
Zn	1	6,950	5,640	81.2	85
	2	6,950	5,040	72.5	85
	3	6,950	5,580	80.3	85
	4	6,950	5,300	76.2	85
	6	6,950	5,140	73.9	85
	8	6,950	5,200	74.8	85
Mean				76.5	
Al	1	64,400	18,300	28.3	28
	2	64,400	18,900	29.4	28
	3	64,400	18,400	28.5	28
	4	64,400	16,900	26.3	28
	6	64,400	17,600	27.3	28
	8	64,400	17,200	26.8	28
Mean				27.8	
Ba	1	707	329	46.6	51
	2	707	311	44.0	51
	3	707	267	37.8	51
	4	707	298	42.1	51
	6	707	304	43.0	51
	8	707	322	45.5	51
Mean				43.2	
Cd	1	21.8	17.0	78.1	92
	2	21.8	17.8	81.4	92
	3	21.8	20.2	92.7	92
	4	21.8	18.8	86.3	92
	6	21.8	17.9	82.2	92
	8	21.8	18.7	85.7	92
Mean				84.4	

Table B-12. Total Extractable Recoveries for NIST SRM 2710 Spiked into Extraction Solution (cont'd.)

Metal	Batch	SRM Certified Concentration (ug/g)	Found Concentration (ug/g)	Percent Recovery	SRM Percent Leachable Recovery
Cu	1	2,950	2,630	89.0	92
	2	2,950	2,490	84.3	92
	3	2,950	2,570	87.2	92
	4	2,950	2,500	84.6	92
	6	2,950	2,490	84.4	92
	8	2,950	2,510	85.0	92
Mean				85.8	
Fe	1	33,800	28,500	84.4	80
	2	33,800	24,100	71.2	80
	3	33,800	27,500	81.4	80
	4	33,800	25,400	75.0	80
	6	33,800	23,400	69.4	80
	8	33,800	23,000	67.9	80
Mean				74.9	
Mn	1	10,100	7,250	71.8	76
	2	10,100	6,890	68.2	76
	3	10,100	7,080	70.1	76
	4	10,100	6,610	65.4	76
	6	10,100	6,860	67.9	76
	8	10,100	6,880	68.2	76
Mean				68.6	
Ni	1	14.3	7.89	55.2	71
	2	14.3	9.89	69.2	71
	3	14.3	8.70	60.8	71
	4	14.3	5.50	38.5	71
	6	14.3	8.39	58.7	71
	8	14.3	7.96	55.6	71
Mean				56.3	

[a]Not certified for SRM.

Table B-13. Total Extractable Recoveries for NIST SRM 2710 Spiked onto Ghost Wipe Media

Metal	Type	Batch	SRM Certified Total Conc. (ug/g)	Found Conc. (ug/sample)	Blank Corrected Conc. (ug/g)	Percent Recovery	SRM Percent Leachable Recovery
As	SRM	1	626	507	507	80.90	94
	Blank	1		0.15			
As	SRM	8	626	543	543	86.80	94
	Blank	8		0.13			
As	SRM	9	626	496	496	79.2	94
	Blank	9		0.12			
Mean						82.3	
Cr[a]	SRM	1	39	14.1	14.0	36.0	49
	Blank	1		0.09			
Cr	SRM	8	39	17.7	11.4	29.3	49
	Blank	8		6.23			
Cr	SRM	9	39	13.8	0.76	1.96	49
	Blank	9		13.0			
Mean (n=3)						22.4	
Mean (n=2)						32.6	
Pb							
	SRM	1	5,530	4,950	4,950	89.5	92
	Blank	1		0.23			
	SRM	8	5,530	5,040	5,040	91.1	92
	Blank	8		0.69			
	SRM	9	5,530	4,500	4,500	81.4	92
	Blank	9		1.08			
Mean						87.3	
Zn							
	SRM	1	6,950	5,570	5,560	80.0	85
	Blank	1		5.11			
	SRM	8	6,950	5,800	5,780	83.2	85
	Blank	8		12.9			
	SRM	9	6,950	5,260	5,240	75.4	85
	Blank	9		23.7			
Mean						79.5	
Al							
	SRM	1	64,400	18,100	18,100	28.2	28
	Blank	1		0.37			
	SRM	8	64,400	20,000	20,000	31.1	28
	Blank	8		2.14			
	SRM	9	64,400	18,500	18,500	28.8	28
	Blank	9		7.71			
Mean						29.3	

Table B-13. Total Extractable Recoveries for NIST SRM 2710 Spiked onto Ghost Wipe Media (cont'd.)

Metal	Type	Batch	SRM Certified Total Conc. (ug/g)	Found Conc. (ug/sample)	Blank Corrected Conc. (ug/g)	Percent Recovery	SRM Percent Leachable Recovery
Ba							
	SRM	1	707	316	309	43.8	51
	Blank	1		6.84			
	SRM	8	707	353	330	46.7	51
	Blank	8		22.7			
	SRM	9	707	324	298	42.2	51
	Blank	9		25.5			
Mean						44.2	
Cd							
	SRM	1	21.8	16.4	16.4	75.0	92
	Blank	1		0.03			
	SRM	8	21.8	18.2	18.1	83.2	92
	Blank	8		0.06			
	SRM	9	21.8	17.9	17.9	81.9	92
	Blank	9		0.02			
Mean						80.1	
Cu							
	SRM	1	2,950	2,540	2,540	86.2	92
	Blank	1		0.02			
	SRM	8	2,950	2,630	2,630	89.3	92
	Blank	8		0.25			
	SRM	9	2,950	2,450	2,450	83.1	92
	Blank	9		0.44			
Mean						86.2	
Fe							
	SRM	1	33,800	27,500	27,500	81.4	80
	Blank	1		0.20			
	SRM	8	33,800	29,100	29,100	86.0	80
	Blank	8		26.7			
	SRM	9	33,800	23,800	23,700	70.2	80
	Blank	9		61.2			
Mean						79.2	
Mn							
	SRM	1	10,100	7,050	7,050	69.8	76
	Blank	1		0.03			
	SRM	8	10,100	7,310	7,300	72.3	76
	Blank	8		10.3			
	SRM	9	10,100	6,980	6,960	68.9	76
	Blank	9		23.3			
Mean						70.3	

Table B-13. Total Extractable Recoveries for NIST SRM 2710 Spiked onto Ghost Wipe Media (cont'd.)

Metal	Type	Batch	SRM Certified Total Conc. (ug/g)	Found Conc. (ug/sample)	Blank Corrected Conc. (ug/g)	Percent Recovery	SRM Percent Leachable Recovery
Ni							
	SRM	1	14.3	7.86	7.86	55.0	71
	Blank	1		0.00			
	SRM	8	14.3	9.96	6.55	45.8	71
	Blank	8		3.42			
	SRM	9	14.3	7.98	0.91	6.34	71
	Blank	9		7.08			
Mean (n=3)						35.7	
Mean (n=2)						50.4	

[a]Not certified for SRM.

Table B-14. Bottle Blank Data Used for Sample Correction and Reagent Blank Data Method 3050B (ng/mL)

	As	Cr	Pb	Zn	Al	Ba	Cd	Cu	Fe	Mn	Ni
For In Vitro 2% HNO_3											
Bottle Blank ID											
TC 1-1	0.13	0.252	0.292	68.0	23.0	125	0.007	1.36	0.006	0.132	0.121
TC 2-1	-0.016	0.059	0.114	10.4	3.46	11	-0.001	0.926	0.0	0.08	0.038
TC 3-1	0.126	0.466	0.293	97.3	31.1	174	0.05	1.51	0.007	0.132	0.208
TC 4-1	0.023	0.035	0.05	7.72	3.29	8.18	0.001	0.23	0.000	0.017	0.015
TC 5-1	0.002	0.109	0.106	54.4	16.2	119	0.001	0.716	0.003	0.043	0.013
TC 6-1	0.005	0.132	0.138	58.5	17.8	126	0.001	1.27	0.003	0.061	0.071
TC 7-1	-0.022	0.027	0.087	9.60	2.81	11.4	0	0.372	0.001	0.023	0.026
TC 8-1	-0.015	0.043	0.07	8.04	3.22	9.04	0	0.42	0.001	0.06	0.009
TC 9-1	-0.031	0.041	0.071	8.63	1.70	7.31	0.002	0.261	0.000	0.012	0.074
Mean (n=9)	0.057	0.129	0.136	35.8	11.4	65.6	0.008	0.784	0.003	0.062	0.064
Std. dev.	0.065	0.145	0.093	34.1	10.9	68.4	0.017	0.499	0.002	0.046	0.066
%RSD	114	112	68.3	95.2	95.6	104.3	222	63.6	98.0	73.1	102
MDL	0.367	0.201	0.082	0.409	1.99	0.668	0.219	0.335	0.006	0.178	0.268
For EPA 3050B 5% HNO_3											
Bottle Blank ID											
TC 1-1	1.04	1.45	6.91	192	128	179	0.088	13.4	0.113	9.40	3.71
TC 2-1	1.28	1.10	2.69	148	85.6	153	0.061	7.63	0.047	2.48	2.91
TC 3-1	0.755	1.29	1.84	157	91.6	197	0.034	3.61	0.042	1.47	2.75
TC 4-1	1.40	48.6	4.407	229	100	193	0.811	7.88	0.191	52.1	27.8
TC 5-1	0.761	5.49	1.65	288	102	192	0.413	14.8	0.034	2.70	2.90
TC 6-1	0.814	3.38	1.54	185	88.5	178	0.19	5.53	0.041	4.15	2.50
TC 7-1	0.383	40.5	0.791	208	90.7	183	1.40	2.90	0.194	48.8	25.6
TC 8-1	0.426	5.67	2.54	182	103	191	0.18	5.31	0.056	9.25	3.24
TC 9-1	1.47	6.97	3.22	170	82.0	169	1.06	8.52	0.029	4.13	7.73
Mean (n=9)	0.925	12.7	2.84	195	96.9	182	0.471	7.72	0.083	14.9	8.80
Std. dev.	0.398	18.3	1.86	42.4	13.9	14.0	0.500	4.08	0.067	20.4	10.3
%RSD	43.0	144	65.3	21.7	14.4	7.7	106	52.8	80.5	136	117
MDL	0.246	0.175	0.092	0.388	2.47	0.634	0.224	0.350	0.004	0.144	0.332
For EPA 3050B Only Reagent Blanks 5% HNO_3 Not Stored in Bottles											
Reagent Blank ID											
TC-4-13	Lost	Lost	Lost	Lost	Lost	Lost	Lost	Lost	Lost	Lost	Lost
TC 5-13	0.936	5.20	1.56	301	92.6	173	0.472	11.3	0.044	2.69	12.3
TC 6-13	0.971	1.02	7.04	166	95.9	168	0.035	6.31	0.109	11.2	2.93
TC 7-13	0.074	8.15	1.39	156	78.6	187	0.314	1.37	0.038	9.01	5.63
TC 9-13	0.382	271	2.76	285	60.8	167	2.74	3.44	1.043	460	152
Mean (n=4)	0.591	71.2	3.19	227	82.0	174	0.890	5.60	0.308	121	43.2
Std. dev.	0.438	133	2.64	76.3	16.0	9.15	1.24	4.28	0.491	226	72.6
%RSD	74.1	187	82.8	33.6	19.5	5.3	140	76.6	159	187	168

Table B-15. Laboratory and Field Ghost Wipe Blank Samples (not blank corrected; ng/mL)

Blank Wipe ID	As	Cr	Pb	Zn	Al	Ba	Cd	Cu	Fe	Mn	Ni
Laboratory Blank Wipes											
For In Vitro 2% HNO_3											
TC 1-11	0.144	0.183	0.282	67.7	13.4	95.6	0.083	1.45	0.006	0.224	0.077
TC 8-12	0.065	0.13	0.695	55.5	12.9	118	0.012	0.944	0.005	0.167	0.034
TC 9-2	0.038	0.113	0.227	57.6	15.3	115	-0.001	0.902	0.003	0.086	0.064
Mean	0.082	0.142	0.401	60.3	13.8	110	0.048	1.099	0.005	0.159	0.058
std dev	0.055	0.037	0.256	6.53	1.29	12.4	0.050	0.306	0.002	0.069	0.022
%RSD	66.9	25.7	63.7	10.8	9.3	11.3	106	27.8	32.7	43.6	37.8
MDL	0.367	0.201	0.082	0.409	1.99	0.668	0.219	0.335	0.006	0.178	0.268
For EPA 3050B 5% HNO_3											
TC 1-11	2.45	2.34	9.20	232	133	261	0.252	9.58	0.114	9.41	2.16
TC 8-12	1.61	67.9	8.10	207	97.5	177	0.777	6.61	0.313	112	37.4
TC 9-2	2.47	136	13.7	297	124	179	1.24	11.6	0.63	246	78.2
Mean	2.17	68.9	10.3	245	118	205	0.75	9.27	0.35	123	39.3
std dev	0.49	67.0	2.95	46.4	18.0	47.8	0.49	2.53	0.26	119	38.0
%RSD	22.6	97.3	28.5	18.9	15.3	23.3	65.2	27.2	73.9	96.8	96.9
MDL	0.25	0.17	0.09	0.39	2.47	0.63	0.22	0.35	0.00	0.14	0.33
Field Blank Wipes											
For In Vitro 2% HNO_3											
TC 8-4	0.043	0.045	0.242	12.9	4.16	9.60	0.084	0.402	0.003	0.157	0.055
TC 8-6	0.037	0.134	9.13	54.8	16.0	115	0.009	0.926	0.005	0.129	0.049
TC 8-7	0.037	0.144	0.2	60.4	20.3	126	0.006	0.857	0.005	0.133	0.058
Mean	0.04	0.11	3.19	42.7	13.5	83.7	0.03	0.73	0.004	0.1400	0.054
std dev	0.00	0.05	5.14	26.0	8.37	64.4	0.04	0.28	0.001	0.015	0.005
%RSD	8.9	50.6	161	60.8	62.0	77.0	134	39.1	26.6	10.8	8.5
Repeat Extract Analysis											
TC 8-6	0.034	0.146	9.27	55.0	15.8	115	0.009	0.926	0.005	0.153	0.048
For EPA 3050B 5% HNO_3											
TC 8-4	1.72	9.68	9.75	246	109	189	1.40	7.75	0.15	19.6	5.960
TC 8-6	1.17	7.37	4.72	209	127	186	0.18	6.30	0.14	14.2	5.04
TC 8-7	1.35	665	7.84	371	138	173	3.01	7.12	2.63	1,170	358
Mean	1.42	227	7.44	276	125	183	1.53	7.06	0.97	401	123
std dev	0.28	379	2.54	85.1	14.9	8.79	1.42	0.73	1.43	666	203
%RSD	19.8	167	34.1	30.9	12.0	4.8	92.6	10.3	148	166	166

Table B-16. Relative Percent Differences (RPD) for the Analysis of Duplicate Aliquots of Tire Crumb Infill from Synthetic Fields and Playground Tire Crumb Samples (µg/g)

Sample	Cr	Pb	Zn	As
Synthetic Field Infill Samples				
F4-L1-S1-A1	0.60	41.1	9,940	0.11
F4-LI-S1-A2	0.25	10.7	5,320	0.08
RPD	84.0	118	60.6	33.3
F4-L1-D1-A1	0.35	24.8	4,880	NR[a]
F4-L1-D1-A2	0.33	47.7	4,070	NR
RPD	6.0	63.2	18.0	
F4-L2-S1-A1	0.14	13.6	2,660	NR
F4-L2-S1-A2	0.37	19.3	4,310	NR
RPD	88.9	34.4	47.6	
F4-L3-S1-A1	1.03	23.7	11,400	0.40
F4-L3-S1-A2	0.98	20.0	8,190	0.28
RPD	5.0	16.7	33.1	35.9
F1-L1-S1-A1	1.01	29.2	17,200	0.55
F1-L1-S1-A2	0.95	18.5	19,200	0.18
RPD	6.2	44.9	10.9	102
F2-L1-S1-A1	0.35	20.6	5,690	0.23
F2-L1-S1-A2	0.92	26.5	9,930	0.24
RPD	90.2	25.3	54.4	3.9
F2-L1-D1-A1	0.36	61.2	5,890	0.18
F2-L1-D1-A2	0.24	36.0	3,120	0.22
RPD	41.1	51.9	61.4	17.7
F1-L3-S1-A1	0.54	20.6	7,930	0.29
F1-L3-S1-A2	0.24	14.4	5,047	0.20
RPD	76.0	35.2	44.4	38.1
F1-L2-S1-A1	0.33	13.1	9,050	0.21
F1-L2-S1-A2	0.54	34.7	8,541	0.25
RPD	47.2	90.2	5.8	21.1
F2-L3-S1-A1	NR	21.6	10,700	0.22
F2-L3-S1-A2	NR	29.1	10,300	0.25
RPD		29.6	3.5	11.4
F2-L2-D1-A1	NR	36.4	10,300	0.44
F2-L2-D1-A2	NR	27.5	10,700	0.24
RPD		27.9	3.19	58.2
F2-L2-S1-A1	NR	33.0	10,500	0.28
F2-L2-S1-A2	NR	30.6	10,100	0.13
RPD		7.7	3.6	74.7
F2-L3-D1-A1	NR	43.7	10,200	0.20
F2-L3-D1-A2	NR	22.4	12,300	0.26
RPD		64.7	18.7	29.1

Table B-16. Relative Percent Differences (RPD) for the Analysis of Duplicate Aliquots of Tire Crumb Infill from Synthetic Fields and Playground Tire Crumb Samples (µg/g) (cont'd.)

	Cr	Pb	Zn	As
Playground Tire Crumb Samples				
P1-LA-TC1	0.52	2.43	9,720	0.15
P1-LA-TC2	1.66	46.3	11,100	0.96
RPD	104	180	13.7	146
P2-TC1	1.61	7.75	18,000	0.25
P2-TC2	2.97	3.42	12,100	0.28
RPD	59.5	77.5	39.4	10.1
P1-LA-TC4	0.72	6.31	6,730	0.28
P1-LA-TC5	0.76	4.64	8,250	0.59
RPD	5.8	30.4	20.3	72.1
P1-LB-TC1	0.76	443	17,500	15.0
P1-LB-TC2	0.26	0.99	6630	0.08
RPD	98.2	199	89.9	198

[a]NR = Not reported.

Table B-17. Recommended Control Limits for In Vitro Soil Quality Control Samples According to EPA Method 9200.1-86

In Vitro QCs	Frequency	Control Limits	Corrective Actions
Reagent Blank	Once per batch	<25 µg/L Pb	Make new fluid and rerun all analyses.
Bottle Blank	5%[a]	<50 µg/L Pb	Check calibration and reanalyze as necessary.
Blank Spike (10 mg/L)	5%[a]	85%-115% recovery	Check calibration and/or source of contamination and reanalyze.
Matrix Spike (10 mg/L)	10%[a]	75%-125% recovery	Flag
Duplicate Sample	10%[a]	±20% RPD[b]	Flag
Control Soil (NIST 2710)	5%[a]	± 10% RPD[c]	Flag

[a]Minimum 1 in 20.
[b]RPD = relative percent difference.
[c]The National Institute of Standards and Technology (NIST) Standard Reference Material (SRM) RPD is based on certified values and mean RBA-Pb values of 75% for SRM 2710.

Table B-18. Summary Control Limit Results for In Vitro Pb Bioaccessibility Quality Control Samples (Note: This method has not been validated for the types of samples collected in this scoping study.)

In Vitro QC Parameters	Analysis Frequency	Control Limit Results	Corrective Actions
Reagent Blank	9 Reagent blank (batches 1-9)	<5 µg/L Pb	None
Bottle Blank	9 Blank runs (batches 1-9)	<5 µg/L Pb	None
Blank Spike (10 mg/L)	8 Blank spike runs (batches 1-8)	90-105% recovery	None
Blank Ghost Wipe with Spike (10 mg/L)	3 Blank wipe with spike runs (batches 1, 8, 9)	87%-99% recovery	None
Blank Ghost Wipe with NIST SRM 2710[b]	3 Wipes with SRM runs (batches 1, 8, 9)	3%-6% RPD[c]	None
NIST SRM 2710[b]	6 SRM runs (batches 1-4, 6, 8)	0%-9% RPD[c]	None
Infill Spike (10 mg/L)	4 Infill spike runs (batches 1-4)	89%-104% recovery	None
Crumb Spike (10 mg/L)	3 Crumb spike runs (batches 1, 5, 9)	87%-103% recovery	None
Duplicate Samples	13 Pairs of infill samples and 4 pairs of crumb samples	2.7%-124% for infill samples and 4%-183% for crumb samples	Noted in report
Blank Ghost Wipe	3 Blank ghost wipe runs (batches 1, 8, 9)	<10 µg/wipe Pb	None

[a]Minimum 1 in 20; matrix spikes for crumbs and infill only performed if enough material was available.
[b]The National Institute of Standards and Technology (NIST) Standard Reference Material (SRM) RPD is based on certified values and mean RBA-Pb values of 75% for SRM 2710.
[c]RPD = relative percent difference.

Table B-19. Percent Recovery Results for In Vitro Blank Spikes

Batch Number	Sample ID	Spiked Amount (mg/L)	Recovered In Vitro Extractable Pb (mg/L)	Percent Spike Recovery
1	Blank Spike	10	9.0	89.7
2	Blank Spike	10	9.9	99.5
3	Blank Spike	10	10.2	102
4	Blank Spike	10	10.2	102
5	Blank Spike	10	10.2	102
6	Blank Spike	10	10.5	105
7	Blank Spike	10	10.0	100
8	Blank Spike	10	10.1	101
Mean				100

Table B-20. Summary of Pb In Vitro Extractable Values for NIST SRM 2710

Batch Number	SRM Certified Concentration (ug/g)	Found Concentration (ug/g)	RPD
1	75.0	81.7	8.9
2	75.0	73.6	1.9
3	75.0	74.1	1.2
4	75.0	79.5	6.0
6	75.0	81.3	8.3
8	75.0	75.3	0.4
Mean	75.0	77.6	4.5

Table B-21. Summary of Pb In Vitro Extractable Values for SRM 2710 Spiked onto Ghost Wipe Media

Type	Batch	SRM %IVBA[a] (based on EPA SOP)	Found (%IVBA)	RPD
SRM	1	75	79.7	6.22
SRM	8	75	78.3	4.39
SRM	9	75	77.6	3.45
Mean			78.5	4.69

[a] In vitro bioaccessibility.

Table B-22. Results for In Vitro Pb Solution Spikes onto Blank Ghost Wipes and Tire Crumb Samples

Media and Spike	Spiked Amount (mg/L)	Net Spiked In Vitro Extractable (mg/L)	Net Media In Vitro Extractable (mg/L)	Media Corrected Spike	Percent Recovery
Pb on Wipes					
Ghost Wipe with Spike	10	8.65		8.65	86.5
Blank Ghost Wipe			0.00		
Ghost Wipe with Spike	10	9.93		9.93	99.3
Blank Ghost Wipe			0.01		
Ghost Wipe with Spike	10	9.66		9.66	96.6
Blank Ghost Wipe			0.00		
Pb on Tire Crumb Infill					
F4-L1-S1-A1 Spiked	10	8.86		8.86	88.6
F4-L1-S1-A1 Unspiked			0.01		
F4-L1-DS1-A1 Spiked	10	10.0		10.0	100
F4-L1-DS1-A1 Unspiked			0.01		
F1-L3-S1-A1 Spiked	10	9.91		9.90	99.0
F1-L3-S1-A1 Unspiked			0.01		
F2-L2-DS1-A1 Spiked	10	10.5		10.5	105
F2-L2-DS1-A1 Unspiked			0.02		
Pb on Tire Crumb					
P1-LA-TC1 Spiked	10	8.88		8.87	88.7
P1-LA-TC1 Unspiked			0.00		
P1-LA-TC4 Spiked	10	10.3		10.3	103
P1-LA-TC4 Unspiked			0.00		
P1-LB-TC1 Spiked	10	10.2		10.2	102
P1-LB-TC1 Unspiked			0.02		

Table B-23. In Vitro Pb Bioaccessibility Extraction Duplicates for Synthetic Turf Field Tire Crumb Infill

Sample	Pb (%IVBA)[a]
F4-L1-S1-A1	1.7
F4-L1-S1-A2	7.3
RPD	124
F4-L1-DS1-A1	3.9
F4-L1-DS1-A2	2.4
RPD	46.3
F4-L2-DS1-A1	3.8
F4-L2-DS1-A2	2.7
RPD	34.7
F4-L3-S1-A1	8.5
F4-L3-S1-A2	10.1
RPD	17.4
F1-L1-S1-A1	9.6
F1-L1-S1-A2	5.3
RPD	57.2
F2-L1-S1-A1	3.7
F2-L1-S1-A2	3.8
RPD	2.7
F2-L1-DS1-A1	1.7
F2-L1-DS1-A2	2.9
RPD	52.9

Sample	Pb (%IVBA)
F1-L3-S1-A1	4.2
F1-L3-S1-A2	4.4
RPD	4.6
F1-L2-S1-A1	5.0
F1-L2-S1-A2	1.6
RPD	105
F2-L3-S1-A1	5.0
F2-L3-S1-A2	4.2
RPD	17.9
F2-L2-DS1-A1	5.0
F2-L2-DS1-A2	4.5
RPD	11.3
F2-L2-S1-A1	7.6
F2-L2-S1-A2	3.6
RPD	72.3
F2-L3-DS1-A1	3.1
F2-L3-DS1-A2	5.5
RPD	54.7
Maximum RPD	124
Minimum RPD	2.7
Number	13

[a]%IVBA = percent in vitro bioaccessibility.

Table B-24. In Vitro Pb Bioaccessibility Extraction Duplicates for Playground Tire Crumb

Sample	Pb (%IVBA)[a]
P1-LA-TC2	4.6
P1-LA-TC3	0.3
RPD	176
P2-TC1	1.8
P2-TC2	7.4
RPD	122
P1-LA-TC4	2.4
P1-LA-TC5	5.2

Sample	Pb (%IVBA)
P1-LB-TC1	0.3
P1-LB-TC2	6.4
RPD	183
Maximum RPD	183
Minimum RPD	73.2
Number	4

[a]%IVBA = percent in vitro bioaccessibility.

Appendix C

Compilation of Environmental Sample Analysis Results

Table C-1. Results of Analysis for Grab VOC Air Samples

Table C-2. Results of Analysis for Particle Mass on Integrated Air Samples

Table C-3. Results of Analysis for Metals in Integrated Air Samples

Table C-4. Results of SEM Analysis for Postulated Tire Crumb Particles on Integrated Air Samples

Table C-5. Results of Analysis of Wet Wipe Samples for Total Extractable Metals

Table C-6. Results of Analysis of Synthetic Turf Field Tire Crumb Infill for Total Extractable Metals

Table C-7. Results of Analysis of Synthetic Turf Field Blades for Total Extractable Metals

Table C-8. Results of Analysis of Playground Tire Crumb for Total Extractable Metals

Table C-9. Results of Analysis of Synthetic Turf Field Infill Sample Analysis for Bioaccessible Pb

Table C-10. Results of Analysis of Synthetic Turf Field Blade Sample Analysis for Bioaccessible Pb

Table C-11. Results of Analysis of Playground Tire Crumb Sample Analysis for Bioaccessible Pb

Table C-1. Results of Analysis for Grab VOC Air Samples

VOC	Site[a]	ppbV Sampling Location at Site[b]				µg/m^3 Sampling Location at Site[b]			
		A	B	C	D	A	B	C	D
Benzene	F1D1	0.090	0.110	0.074	0.073	0.287	0.351	0.223	0.223
	F1D2	0.081	0.081	0.088	0.092	0.255	0.255	0.287	0.287
	F2	0.098	0.120	0.120	0.120	0.319	0.383	0.383	0.383
	F4	0.320	0.120	0.160	0.120	1.021	0.383	0.510	0.383
	P1	0.088	0.086	—[c]	0.087	0.287	0.287	—	0.287
Toluene	F1D1	0.140	0.98	0.140	0.150	0.527	3.688	0.527	0.564
	F1D2	0.120	0.110	0.110	0.120	0.452	0.414	0.414	0.452
	F2	0.180	0.180	0.190	0.190	0.677	0.677	0.715	0.715
	F4	0.510	0.190	0.150	0.190	1.919	0.715	0.564	0.715
	P1	0.140	0.430	—	0.160	0.527	1.618	—	0.602
m&p-Xylenes	F1D1	ND[d]	0.170	ND	0.083	ND	0.737	ND	0.347
	F1D2	0.075	0.130	ND	ND	0.303	0.564	ND	ND
	F2	0.047	0.074	0.091	0.077	0.217	0.303	0.390	0.347
	F4	0.290	0.055	0.077	ND	1.257	0.217	0.347	ND
	P1	ND	0.130	—	0.050	ND	0.564	—	0.217
o-Xylene	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	0.120	ND	ND	ND	0.520	ND	ND	ND
	P1	ND	0.045	—	ND	ND	0.173	—	ND
Ethylbenzene	F1D1	ND	0.073	ND	ND	ND	0.303	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	0.110	ND	ND	ND	0.477	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
1,2,4-Trimethylbenzene	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	0.082	ND	ND	ND	0.393	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
4-Ethyltoluene	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	0.082	ND	ND	ND	0.393	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
Hexane	F1D1	ND	0.320	0.092	0.063	ND	1.126	0.317	0.211
	F1D2	0.098	0.062	ND	0.078	0.352	0.211	ND	0.281
	F2	ND	0.049	0.110	0.045	ND	0.176	0.387	0.141
	F4	0.150	0.110	0.160	0.049	0.528	0.387	0.563	0.176
	P1	ND	0.300	—	ND	ND	1.055	—	ND

Table C-1. Results of Analysis for Grab VOC Air Samples (cont'd.)

VOC	Site[a]	ppbV Sampling Location at Site[b]				µg/m^3 Sampling Location at Site[b]			
		A	B	C	D	A	B	C	D
Cyclohexane	F1D1	ND	0.330	ND	ND	ND	1.134	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	0.250	—	ND	ND	0.859	—	ND
Methyl Ethyl Ketone	F1D1	0.400	0.560	0.440	0.440	1.180	1.651	1.298	1.298
	F1D2	0.490	0.340	0.320	0.360	1.445	1.003	0.94	1.062
	F2	0.400	0.440	0.380	0.370	1.180	1.298	1.121	1.091
	F4	0.370	0.500	0.410	0.440	1.091	1.474	1.209	1.298
	P1	0.340	0.480	—	0.380	1.003	1.415	—	1.121
Methyl Isobutyl Ketone	F1D1	0.088	0.110	0.180	ND	0.368	0.450	0.736	ND
	F1D2	0.120	0.110	ND	ND	0.491	0.450	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
2-Hexanone	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	0.046	ND	ND	ND	0.204	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
Carbon Tetrachloride	F1D1	0.090	0.092	0.084	0.097	0.566	0.579	0.528	0.610
	F1D2	0.097	0.100	0.093	0.098	0.610	0.629	0.585	0.616
	F2	0.088	0.100	0.092	0.084	0.554	0.629	0.579	0.528
	F4	0.088	0.089	0.086	0.098	0.554	0.560	0.541	0.616
	P1	0.083	0.082	—	0.094	0.522	0.516	—	0.0.591
Dichlorodifluoromethane	F1D1	0.519	0.540	0.500	0.550	2.566	2.670	2.472	2.720
	F1D2	0.490	0.530	0.470	0.560	2.423	2.621	2.324	2.769
	F2	0.500	0.640	0.540	0.510	2.472	3.165	2.670	2.522
	F4	0.470	0.480	0.490	0.540	2.324	2.373	2.423	2.670
	P1	0.520	0.540	—	0.540	2.571	2.670	—	2.670
Methylchloride	F1D1	0.430	0.500	0.470	0.480	0.888	1.033	0.97	0.99
	F1D2	0.460	0.470	0.470	0.460	0.95	0.97	0.97	0.95
	F2	0.420	0.460	0.470	0.450	0.867	0.95	0.971	0.93
	F4	0.470	0.500	0.470	0.520	0.97	1.033	0.97	1.074
	P1	0.470	0.450	—	0.450	0.97	0.93	—	0.93
Trichlorofluoromethane	F1D1	0.250	0.280	0.260	0.280	1.405	1.573	1.461	1.573
	F1D2	0.260	0.260	0.250	0.270	1.461	1.461	1.405	1.517
	F2	0.250	0.290	0.270	0.250	1.405	1.630	1.517	1.405
	F4	0.240	0.240	0.240	0.300	1.349	1.349	1.349	1.686
	P1	0.260	0.260	—	0.260	1.461	1.461	—	1.461

Table C-1. Results of Analysis for Grab VOC Air Samples (cont'd.)

VOC	Site[a]	ppbV Sampling Location at Site[b]				µg/m^3 Sampling Location at Site[b]			
		A	B	C	D	A	B	C	D
Trichlorotrifluoroethane	F1D1	0.080	0.081	0.075	0.081	0.613	0.613	0.537	0.613
	F1D2	0.077	0.079	0.076	0.084	0.613	0.613	0.613	0.613
	F2	0.073	0.085	0.075	0.072	0.537	0.613	0.537	0.537
	F4	0.069	0.072	0.072	0.150	0.537	0.537	0.537	1.150
	P1	0.074	0.074	—	0.074	0.537	0.537	—	0.537
Methylene Chloride	F1D1	ND	0.074	0.062	0.062	ND	0.243	0.208	0.208
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	0.058	0.069	0.062	0.059	0.208	0.243	0.208	0.208
	F4	0.055	0.055	0.065	0.061	0.208	0.174	0.208	0.208
	P1	0.071	0.110	—	0.066	0.243	0.382	—	0.243
Chloroform	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	0.062	ND	ND	ND	0.293	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
1,1,1-Trichloroethane	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
1,1,2,2-Tetrachloroethane	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
1,1,2-Trichloroethane	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
1,1-Dichloroethane	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
1,1-Dichloroethylene	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
1,2,4-Trichlorobenzene	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND

Table C-1. Results of Analysis for Grab VOC Air Samples (cont'd.)

VOC	Site[a]	ppbV Sampling Location at Site[b]				µg/m^3 Sampling Location at Site[b]			
		A	B	C	D	A	B	C	D
1,2-Dibromoethane	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
1,2-Dichlorobenzene	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
1,2-Dichloroethane	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
1,2-Dichloropropane	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
1,3,5-Trimethylbenzene	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
1,3-Butadiene	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
1,3-Dichlorobenzene	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
1,4-Dichlorobenzene	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
Acrylonitrile	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND

Table C-1. Results of Analysis for Grab VOC Air Samples (cont'd.)

VOC	Site[a]	ppbV Sampling Location at Site[b]				µg/m^3 Sampling Location at Site[b]			
		A	B	C	D	A	B	C	D
Allyl Chloride	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
Benzylchloride	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
Bromodichloromethane	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
Bromoform	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
cis-1,2-Dichloroethylene	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
cis-1,3-Dichloropropylene	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
Chlorobenzene	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
Chloroethane	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
Dibromochloromethane	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND

Table C-1. Results of Analysis for Grab VOC Air Samples (cont'd.)

VOC	Site[a]	ppbV Sampling Location at Site[b]				µg/m^3 Sampling Location at Site[b]			
		A	B	C	D	A	B	C	D
Dichlorotetrafluoroethane	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
Heptane	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
Hexachloro-1,3-butadiene	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
Methylbromide	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
Methyl-t-Butyl Ether	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
Styrene	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
trans-1,2-Dichloroethylene	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
trans-1,3-Dichloropropylene	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
Tetrachloroethylene	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND

Table C-1. Results of Analysis for Grab VOC Air Samples (cont'd.)

VOC	Site[a]	ppbV Sampling Location at Site[b]				µg/m^3 Sampling Location at Site[b]			
		A	B	C	D	A	B	C	D
Tetrahydrofuran	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
Trichloroethylene	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
Vinyl Bromide	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND
Vinylchloride	F1D1	ND	ND	ND	ND	ND	ND	ND	ND
	F1D2	ND	ND	ND	ND	ND	ND	ND	ND
	F2	ND	ND	ND	ND	ND	ND	ND	ND
	F4	ND	ND	ND	ND	ND	ND	ND	ND
	P1	ND	ND	—	ND	ND	ND	—	ND

[a]Site identification: P = playground; F = synthetic turf field; D = day 1 or day 2.
[b]Sampling location: A, B, and C are "on field" or "on playground"; D is "upwind background."
[c]Only two "on playground" sampling locations.
[d]ND = not detected.

Table C-2. Results of Analysis for Particle Mass on Integrated Air Samples (µg/m^3)

Site[a]	Sampling Location[b]						
	A	A Dup	B	B Dup	C	D	Field Blank
F1D1	27.5	—[c]	28.6	29.0	27.4	29.5	0.6
F1D2	29.6	—	30.0	—	—	29.5	0.4
F4	33.4	31.0	30.9	—	31.0	28.6	0.7
P1	23.9	24.3	29.5	—	—	14.2	0.2

[a]F = turf field, P = playground, D = day, Dup = duplicate sample.
[b]A, B, and C are "on field" or "on playground," D is "upwind background."
[c]Not collected.

Table C-3. Results of Analysis for Metals in Integrated Air Samples (ng/m^3)[a]

Site and Sampling Location at the Site[b]	Pb	Cr	Zn	Ca	Cl	Cu	Fe	K	Mn	S	Si	Ti
F1D1 location A	—[c]	2.3	6.6	449	14.1	8.9	230	134	6.1	4,004	1,291	20.4
F1D1 location B	—	—	15.3	230	—	—	201	91.7	—	3,688	555	30.8
F1D1 location B duplicate	—	2.8	13.6	370	—	—	199	99.2	6.3	3,018	1,497	22.3
F1D1 location C	—	3.6	10.6	349	—	—	226	126	—	3,946	796	24.7
F1D1 location D	—	2.0	23.8	396	—	—	240	128	7.5	3,667	1,405	25.2
F1D1 field blank	—	—	—	34.5	12.2	—	—	8.6	—	—	—	—
F1D2 location A	7.7	4.3	17.0	834	21.0	10.3	364	164	9.3	3,680	1,248	29.4
F1D2 location B	—	2.8	6.6	812	—	—	364	158	10.6	3,784	858	27.9
F1D2 location C	NR[d]	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
F1D2 location D	6.3	3.3	11.6	881	20.9	—	356	178	8.4	3,933	1,548	31.9
F1D2 field blank	—	—	9.5	—	—	—	—	—	4.3	—	—	—
F4 location A	—	3.4	36.0	487	25.5	21.3	803	302	18.5	3,044	2,646	58.7
F4 location A duplicate	—	5.0	31.9	303	—	20.0	559	191	13.0	1,516	2,116	44.0
F4 location B	—	—	33.0	338	—	13.4	663	228	13.4	2,845	1,912	58.2
F4 location C	—	—	25.2	319	—	12.2	573	238	10.9	2,952	1,942	51.4
F4 location D	—	2.7	21.7	466	21.1	12.3	456	227	10.9	2,976	1,890	41.2
F4 field blank	—	—	—	12.9	—	—	—	—	—	—	—	—
P1 location A	5.1	3.6	90.7	317	118	11.8	672	196	8.6	664	2,784	57.6
P1 location A duplicate	—	2.5	82.5	365	177	—	748	240	13.6	882	2,435	63.7
P1 location B	—	3.1	117	414	189	—	987	312	15.0	903	3,455	92.3
P1 location D	—	—	10.5	238	95.5	10.8	294	97.2	—	751	516	21.4
P1 field blank	—	—	—	—	—	—	—	—	—	—	—	—

[a]Values represent those less than three times the measurement uncertainty limit following field blank corrections.
[b]F = turf field, P = playground, D = day, Dup = duplicate sample. [b]Designations A, B, and C refer to "on field" or "on playground" locations; D locations represent background sites.
[c]— Represents values less than three times the measurement uncertainty limit.
[d]NR = sample filter inverted during collection; analysis results not reported.

Table C-4. Results of SEM Analysis for Postulated Tire Crumb Particles on Integrated Air Samples[a]

Sample ID[b]	Number of Postulated Tire Crumb Particles[c]	Mass of Postulated Tire Crumb Particles[c] (pg)	Scaled Mass of Postulated Tire Crumb Particles[d] (µg)	Estimated Concentration of Postulated Tire Crumb Particles (µg/m^3)
F1D1 location A	5	6	0.01	0.001
F1D1 location A duplicate	15	80	0.02	0.004
F1D1 location A dup. Repeat	5	65	0.03	0.007
F1D1 location B	18	90	0.08	0.019
F1D1 location D	7	16	0.01	0.003
F4 location A	0	0	0.00	0.000
F4 location A duplicate	4	19	0.01	0.003
F4 location B	6	47	0.03	0.007
F4 location D	6	15	0.01	0.002
P1 location A	63[e]	3,330	3.9	0.77
P1 location B	58[f]	2,530	2.1	0.42
P1 location D	5	40	0.03	0.005

[a]Given the lack of unique composition and morphology for tire crumb particles from the collected materials, the estimates in this table have considerable uncertainty.
[b]F= synthetic turf field; P = playground; A and B are “on field” or “on playground;” D = “upwind background.”
[c]Raw numbers, not normalized to the same analyzed area. (CCSEM areas analyzed ranged from 0.6 mm^2 to 3.6 mm^2).
[d]Estimated tire crumb mass scaled to total exposed filter area of 6.7 cm^2.
[e]Mass median diameter ~2.6 µm.
[f]Mass median diameter ~2.2 µm.

Table C-5. Results of Analysis of Wet Wipe Samples for Total Extractable Metals (µg/ft^2; based on total extractable amounts from consecutive in vitro and Method 3050B extractions)

Site and Sample Location[a]		Pb	Cr	Zn	Al	As	Ba	Cd	Cu	Fe	Mn	Ni
F1D1	Loc. A, S	0.500	0.112	35.9	19.5	0.051	NR	<MDL[b]	2.97	77.1	0.738	0.241
F1D1	Loc. A, DS	0.489	0.178	43.3	26.3	0.055	0.351	<MDL	3.59	104	0.923	0.123
F1D1	Loc. B, S[c]	1.46	0.413	34.4	27.0	0.062	0.083	<MDL	2.77	91.0	1.09	0.221
F1D1	Loc. B, DS[c]	1.91	0.517	38.4	22.5	0.102	NR	0.022	2.61	81.3	1.13	0.184
F1D1	Loc. C, S	0.347	0.214	30.9	18.6	0.033	5.05	<MDL	2.06	74.2	0.690	0.149
F1D1	Loc. C, DS	0.323	0.077	21.3	17.3	0.028	NR	<MDL	1.69	71.5	0.598	0.177
F1D2	Loc. A, S	0.370	0.096	26.4	17.6	0.045	NR	<MDL	2.05	68.6	0.741	0.065
F1D2	Loc. A, DS	0.407	0.197	34.9	21.1	0.039	NR	<MDL	2.68	87.7	0.882	0.122
F1D2	Loc. B, S[c]	0.731	0.278	37.4	30.4	0.050	0.387	0.008	2.79	100	1.02	0.165
F1D2	Loc. B, DS[c]	1.39	NR[d]	29.1	28.9	0.058	0.564	NR	2.20	87.3	0.356	NR
F1D2	Loc. C, S	0.688	NR	40.6	30.0	0.049	0.280	NR	2.69	91.5	NR	NR
F1D2	Loc. C, DS	0.346	NR	25.7	18.2	0.045	NR	NR	1.92	75.6	NR	NR
F2	Loc. A, S	0.456	NR	19.3	52.1	0.049	0.125	NR	0.677	116	NR	NR
F2	Loc. B, S	0.280	NR	13.0	28.0	0.026	7.31	<MDL	0.549	78.9	NR	NR
F2	Loc. C, S	0.289	NR	9.24	33.3	0.024	1.16	NR	0.488	74.8	NR	NR
F4	Loc. A, S	0.177	NR	5.28	42.7	0.022	0.085	NR	0.326	61.3	NR	NR
F4	Loc. A, DS	0.139	NR	4.25	36.1	0.018	0.384	<MDL	0.280	49.5	NR	NR
F5	Loc. B, S	0.129	NR	6.29	19.6	0.020	6.10	NR	0.203	28.5	NR	NR
F6	Loc. C, S	0.184	0.245	13.6	16.4	0.027	5.94	0.006	0.305	33.7	0.520	NR
F1D1	Field Blank	0.181	0.096	1.79	0.17	0.034	NR	0.033	0.057	2.28	0.253	0.067
F4	Field Blank	0.541	0.046	3.17	1.25	0.021	5.60	<MDL	0.051	2.15	0.124	0.046
F4	Field Blank	0.135	16.0	7.36	1.76	0.025	5.84	0.068	0.067	62.1	27.1	8.54

[a]F = synthetic turf field; D = day 1 or day 2; Loc. = "on field" sampling location at site, S = sample collected at the location, DS = duplicate sample collected immediately adjacent to the sample.
[b]<MDL = extract concentration less than the method detection limit in both in vitro and Method 3050B analyses.
[c]Location B wipe samples from red synthetic turf in end zone.
[d]NR = not reported; analytical result <0 after blank correction.

Table C-6. Results of Analysis of Synthetic Turf Field Tire Crumb Infill for Total Extractable Metals (µg/g; based on total extractable amounts from consecutive in vitro and Method 3050B extractions)

Site, Sampling Location, Sample, and Aliquot[a]		Pb	Cr	Zn	Al	As	Ba	Cd	Cu	Fe	Mn	Ni
F1	L1, S1, A1	29.2	1.01	17,200	218	0.55	68.4	0.87	23.7	416	4.54	8.95
F1	L1, S1, A2	18.5	0.95	19,200	233	0.18	7.01	0.97	24.0	535	13.6	7.55
F1	L2, S1, A1	13.1	0.33	9,050	168	0.21	NR	0.79	8.73	196	3.16	2.50
F1	L2, S1, A2	34.7	0.54	8,540	167	0.25	NR	0.81	6.54	168	3.25	2.04
F1	L3, S1, A1	20.6	0.54	7,930	170	0.29	NR	1.05	7.96	241	3.94	3.52
F1	L3, S1, A2	14.4	0.24	5,050	171	0.20	NR	0.69	2.64	150	3.48	2.44
F2	L1, S1, A1	20.6	0.35	5,690	345	0.23	NR	0.35	3.46	215	4.66	0.78
F2	L1, S1, A2	26.5	0.92	9,930	533	0.24	56.0	0.60	10.7	476	3.85	1.95
F2	L1, DS1, A1	61.2	0.36	5,890	473	0.18	37.5	0.55	2.63	209	3.71	0.82
F2	L1, DS1, A2	36.0	0.24	3,120	376	0.22	5.67	0.68	1.18	134	3.36	0.70
F2	L2, S1, A1	33.0	NR[b]	10,500	347	0.28	35.8	0.46	13.6	228	NR	NR
F2	L2, S1, A2	30.6	NR	10,100	330	0.13	18.3	0.37	15.8	210	NR	NR
F2	L2, DS1, A1	36.4	NR	10,300	289	0.44	26.4	1.05	16.8	429	NR	NR
F2	L2, DS1, A2	27.5	NR	10,700	309	0.24	12.3	0.47	14.1	227	NR	NR
F2	L3, S1, A1	21.6	NR	10,700	368	0.22	44.7	0.47	14.4	247	NR	NR
F2	L3, S1, A2	29.1	NR	10,300	386	0.25	43.5	0.45	14.2	283	NR	NR
F2	L3, DS1, A1	43.7	NR	10,200	426	0.20	98.5	0.52	14.6	239	NR	NR
F2	L3, DS1, A2	22.4	NR	12,300	373	0.26	76.6	0.68	17.2	269	NR	NR
F4	L1, S1, A1	41.1	0.60	9,940	307	0.11	21.0	0.29	7.32	160	2.27	0.94
F4	L1, S1, A2	10.7	0.25	5,320	290	0.08	15.7	0.30	1.54	125	1.59	0.37
F4	L1, DS1, A1	24.8	0.35	4,880	328	-0.03	71.1	<MDL	2.47	232	3.92	<MDL
F4	L1, DS1, A2	47.7	0.33	4,070	268	<MDL	39.2	<MDL	2.13	154	3.82	<MDL
F5	L1, S1, A1	13.6	<MDL[c]	2,660	201	<MDL	18.7	<MDL	1.01	104	4.01	<MDL
F5	L1, S1, A2	19.3	<MDL	4,310	269	<MDL	32.1	<MDL	2.57	111	2.79	<MDL
F6	L1, S1, A1	23.7	1.03	11,400	456	0.40	42.6	1.55	13.6	539	7.91	2.17
F6	L1, S1, A2	20.0	0.98	8,190	555	0.28	33.9	1.36	8.5	745	8.73	1.41

[a]F = synthetic turf field; L = site sampling location; S = sample collected at the location; DS = duplicate sample collected at the location; A = aliquot of tire crumb infill from sample (~1 g each).
[b]NR = not reported; analytical result <0 after blank correction.
[c]<MDL = extract concentration less than the method detection limit in both in vitro and Method 3050B analyses.

Table C-7. Results of Analysis of Synthetic Turf Blades for Total Extractable Metals (µg/g; based on total extractable amounts from consecutive in vitro and Method 3050B extractions)

Site and Blade Color[a]		Pb	Cr	Zn	Al	As	Ba	Cd	Cu	Fe	Mn	Ni
F1	Red	389	73.1	351	1,090	0.40	141	0.16	5.83	738	7.70	1.96
F1	Green	3.84	9.71	316	2,090	0.47	88	0.07	44.8	2,060	9.41	3.22
F1	White	4.28	0.99	688	1,320	0.60	114	NR[b]	7.42	721	6.83	3.98
F1	Black	2.76	1.91	729	1,290	0.29	111	NR	5.91	787	6.02	1.00
F3	Red	2.40	1.20	199	947	0.22	1,950	NR	3.19	449	8.35	0.10
F3	White	1.97	0.08	255	336	NR	38	NR	1.54	138	3.36	1.66
F4	Green, white, yellow mix	2.08	3.72	206	2,120	0.25	50	NR	74.1	4,950	12.07	2.94
F5	Green, white, yellow mix[c]	701	177	131	1,620	0.12	40	<MDL[d]	68.3	3,300	6.05	2.43
F6	Green, white, yellow mix	77.1	18.9	175	1,150	0.05	303	NR	34.9	3,230	4.94	14.3

[a]F = synthetic turf fields.
[b]NR = not reported; analytical result <0 after blank correction.
[c]Blade samples collected from a field with an apparently patched area. Also, the Method 3050B extract for this sample spilled during processing.
[d]<MDL = extract concentration less than the method detection limit in both in-vitro and Method 3050B analyses.

Table C-8. Results of Analysis of Playground Tire Crumb for Total Extractable Metals (µg/g; based on total extractable amounts from consecutive in vitro and Method 3050B extractions)

Site, Sampling Location, and Tire Crumb Piece[a]		Pb	Cr	Zn	Al	As	Ba	Cd	Cu	Fe	Mn	Ni
P1	Loc. A, TC 1	0.99	0.28	4,330	96.4	0.04	5.70	0.09	0.05	37.2	0.47	0.24
P1	Loc. A, TC 2	2.43	0.52	9,717	92.3	0.15	0.72	0.34	1.02	82.3	1.29	0.25
P1	Loc. A, TC 3	46.3	1.66	11,100	372	0.96	18.9	6.14	1.82	384	4.58	1.60
P1	Loc. A, TC 4	6.31	0.72	6,730	138	0.28	3.75	0.84	2.83	154	2.81	0.62
P1	Loc. A, TC 5	4.64	0.76	8,250	799	0.59	3.46	0.11	1.66	274	1.86	2.09
P1	Loc. B, TC 1	443	0.76	17,500	350	15.0	13.3	10.5	3.74	320	8.83	2.48
P1	Loc. B, TC 2	0.99	0.26	6,630	44.3	0.08	1.89	0.05	1.26	57.4	2.24	0.79
P2	TC 1	7.75	1.61	18,000	126	0.25	8.46	0.21	2.74	1,900	7.76	1.69
P2	TC 2	3.42	2.97	12,100	170	0.28	11.0	0.67	4.98	6,180	4.27	1.11

[a]P = playground; Loc. = sampling location; TC = different pieces of tire crumb from two sampling locations at site P1 were analyzed; two pieces of tire crumb from site P2 were analyzed.

Table C-9. Results of Analysis of Synthetic Turf Field Infill Sample Analysis for Bioaccessible Pb

Site, Sampling Location, Sample, and Aliquot[a]		Total Extractable Pb (µg/g)	Pb In Vitro Bioaccessibility Value (%)[b]
F1	L1, S1, A1	29.2	9.6
F1	L1, S1, A2	18.5	5.3
F1	L2, S1, A1	13.1	5.0
F1	L2, S1, A2	34.7	1.6
F1	L3, S1, A1	20.6	4.2
F1	L3, S1, A2	14.4	4.4
F2	L1, S1, A1	20.6	3.7
F2	L1, S1, A2	26.5	3.8
F2	L1, DS1, A1	61.2	1.7
F2	L1, DS1, A2	36.0	2.9
F2	L2, S1, A1	33.0	7.6
F2	L2, S1, A2	30.6	3.6
F2	L2, DS1, A1	36.4	5.0
F2	L2, DS1, A2	27.5	4.5
F2	L3, S1, A1	21.6	5.0
F2	L3, S1, A2	29.1	4.2
F2	L3, DS1, A1	43.7	3.1
F2	L3, DS1, A2	22.4	5.5
F4	L1, S1, A1	41.1	1.7
F4	L1, S1, A2	10.7	7.3
F4	L1, DS1, A1	24.8	3.9
F4	L1, DS1, A2	47.7	2.4
F5	L1, S1, A1	13.6	3.8
F5	L1, S1, A2	19.3	2.7
F6	L1, S1, A1	23.7	8.5
F6	L1, S1, A2	20.0	10.1
Mean			*4.7 ± 2.3*
Minimum			*1.6*
Maximum			*10.1*

[a]L = sampling location at site, S = sample collected at the location, DS = duplicate sample collected at the location, A = aliquot of tire crumb infill from sample (~1 g each).
[b]The in vitro bioaccessibility values were determined by dividing the amount of Pb extracted in the in vitro extraction by the total extractable amount of Pb.

Table C-10. Results of Analysis of Synthetic Turf Field Blade Sample Analysis for Bioaccessible Pb

Site[a] and Blade Color		Total Extractable Pb (µg/g)	Pb In Vitro Bioaccessibility Value (%)[a]
F1	Red	389	2.3
F1	Green	3.84	40.9
F1	White	4.28	43.0
F1	Black	2.76	86.8
F3	Red	2.40	40.3
F3	White	1.97	38.7
F4	Green, white, yellow mix	2.08	54.4
F5	Green, white, yellow mix	701	0.2
F6	Green, white, yellow mix	77.1	1.0
Mean			*34.2 ± 28.8*
Minimum			*0.2*
Maximum			*86.8*

[a] F = field site.
[b]The in vitro bioaccessibility values were determined by dividing the amount of Pb extracted in the in vitro extraction by the total extractable amount of Pb.

Table C-11. Results of Analysis of Playground Tire Crumb Sample Analysis for Bioaccessible Pb

Site, Sampling Location, and Tire Crumb Piece[a]		Total Extractable Pb (µg/g)	Pb In Vitro Bioaccessibility Value (%)[b]
P1	Loc. A, TC1	0.99	10.7
P1	Loc. A, TC2	2.43	4.6
P1	Loc. A, TC3	46.3	0.3
P1	Loc. A, TC4	6.31	2.4
P1	Loc. A, TC5	4.64	5.2
P1	Loc. B, TC1	443	0.3
P1	Loc. B, TC2	0.99	6.4
P2	TC1	7.75	1.8
P2	TC2	3.42	7.4
Mean			*4.3 ± 3.5*
Minimum			*0.3*
Maximum			*10.7*

[a]L = sampling location at site, TC = tire crumb piece analyzed from the location.
[b]The in vitro bioaccessibility values were determined by dividing the amount of Pb extracted in the in vitro extraction by the total extractable amount of Pb.

A Survey of Microbial Populations in Infilled Synthetic Turf Fields

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1855

A DRAFT REPORT BY FACULTY OF THE
CENTER FOR TURFGRASS SCIENCE AT PENN STATE

A Survey of Microbial Populations in Infilled Synthetic Turf Fields

Introduction

Staphylococcus aureus is a bacterium that is a common inhabitant of human skin and can cause various types of skin or soft tissue infections (Marples, et al, 1990). *S. aureus* has also been implicated in certain types of food poisoning (Bennet and Lancette, 1998) and in serious medical problems such as toxic shock syndrome. Strains of *S. aureus* that are resistant to common antibiotics are becoming more common, particularly in medical settings. There have been reports recently of methicillin-resistant *S. aureus* causing infection in athletes (Begier, et al, 2004). With the increase in athlete infections, there is growing concern regarding the role of infilled turf systems (Seppa, 2005). While there is some indication that the source of these bacteria may be more closely associated with locker room activity than with the infill system (Begier, et al, 2004; Kazakova, et al, 2005), conclusive evidence is not currently available.

The objective of this survey was to determine the microbial population of several infilled synthetic turf systems as well as natural turfgrass fields. In addition, other surfaces from public areas and from an athletic training facility were also sampled. Colonies suspected to be *S. aureus* were positively or negatively identified.

Materials & Methods

Sample Collection

All samples in this study were collected between June 15 and June 30, 2006. Infilled synthetic turf systems were located at facilities in Pennsylvania and were in use by all levels of play ranging from elementary to professional athletes. Crumb rubber samples were collected from both a 'high use' and a 'low use' area of each field. A 'high use' area typically was a goal mouth or, for a football only field, an area between the 30- and 40-yard lines between the hash marks. A 'low use' area was typically an area toward the edge of the field (but within the field of play) or an end zone. Approximately 2-3 ml of crumb rubber were removed from each area of the field using a sterile test tube inserted directly into the infill. Pile fiber samples were also collected from many fields by clipping several fibers from the backing and transferring the fibers to a sterile test tube. Samples were stored in a cooler and processed as soon after collection as possible.

Sample Processing

Approximately 0.075 g of crumb rubber was transferred to a test tube containing 10 ml sterile 0.1% peptone broth. The sample was agitated for 30 seconds. Serial dilutions of each sample were plated up to 10^{-3} on both R2A agar for total organism populations and Baird-Parker agar, a selective media for *Staphylococcus* (Bennet and Lancette, 1998). Duplicate platings were made for each media and each dilution. Petri plates were parafilmed and incubated at room temperature and colony counts were made 72 hours after processing. Samples on Baird-Parker agar were also observed again after 5 days. Calculations were then made to determine the number of colony forming units (CFU) per gram of crumb rubber.

For comparison purposes, soil samples were also collected from a native soil and a sand based natural turfgrass athletic field. Samples were processed in the same manner as the crumb rubber samples with 0.2 grams of soil being used for processing.

Sampling of Other Surfaces

Samples were collected from common surfaces in public areas as well as from various surfaces in an athletic training area. Samples were collected by swabbing surfaces with sterile cotton swabs. Random individuals were also tested by swabbing hands and/ or face. Both R2A and Baird-Parker agar plates were wiped with the sterile swabs. Plates were incubated at room temperature and colony counts were conducted after 72 hours for R2A agar and again at 5 days for Baird-Parker media.

Identification of *Staphylococcus aureus* colonies

Gram stains and latex agglutination tests (Essers and Radebold, 1980) were performed on colonies suspected of being *S. aureus*. Several potential *S. aureus* colonies isolated from hand and facial swabs were also included in the testing.

Results

Field Samples

The results of total microbial populations are shown in Table 1. While microbes exist in the infill media the number was low compared to natural turfgrass field soils. It should be remembered that microbes tend to be present on most surfaces humans come in contact with and the simple presence of microbes should not be cause for concern. In fact, many products on the market claim to boost the microbial populations of natural turfgrass soils with higher microbial populations considered to be beneficial.

Table 1. Colony forming units (CFU) detected on R2A media per gram of crumb rubber.

Field ID#[1]	Product	CFU/ g crumb rubber
1H	100% crumb rubber	20200
1L	100% crumb rubber	32667
2H	Crumb rubber - Sand mix	3533
2L	Crumb rubber - Sand mix	133
3H	Crumb rubber - Sand mix	3467
3L	Crumb rubber - Sand mix	13133
4H	100% crumb rubber	9467
4L	100% crumb rubber	30267
5H	Crumb rubber - Sand mix	18867
5L	Crumb rubber - Sand mix	8333
6H	Crumb rubber - Sand mix	267
6L	Crumb rubber - Sand mix	28333
7H	Crumb rubber - Sand mix	4800
7L	Crumb rubber - Sand mix	55333
8H	Crumb rubber - Sand mix	4867
8L	Crumb rubber - Sand mix	24133
9H	100% crumb rubber	9800
9L	100% crumb rubber	17867
10H*	Crumb rubber - Sand mix	0
10L*	Crumb rubber - Sand mix	67
11H	Crumb rubber - Sand mix	33200
11L	Crumb rubber - Sand mix	28000
12H	100% crumb rubber	333
12L	100% crumb rubber	800
13H*	100% crumb rubber	267
13L*	100% crumb rubber	67
14H	100% crumb rubber	8267
15H	Crumb rubber - Sand mix	8600
15L	Crumb rubber - Sand mix	3867
16H*	100% crumb rubber	200
16L*	100% crumb rubber	0
17H	Crumb rubber - Sand mix	0
17L	Crumb rubber - Sand mix	7267
18H	100% crumb rubber	5000
18L	100% crumb rubber	5533
18H	Crumb rubber - Sand mix	53067
18L	Crumb rubber - Sand mix	80000
20H	Crumb rubber - Sand mix	54333
20L	Crumb rubber - Sand mix	8867
Native soil (silt loam)		259500
Sand based soil		309500

[1] H = sample collected from higher use area of field
L = sample collected from lower use area of field
* = sample collected from indoor field

Pile fiber samples were also collected from several fields. CFUs for fiber samples range from 200-2933 CFUs per fiber sample (2 fibers approximately 1 cm long) indicating that the fibers alone generally exhibited lower microbial populations compared to the infill.

Microbial colonies isolated from field samples generally included both fungi and bacteria. Some fields had predominantly one organism type while other fields contained a variety of organisms. In order to positively identify the presence of S. aureus, three procedures were used. No colonies isolated from any crumb rubber or fiber samples tested positive for *S. aureus* via selective media, gram stain or latex agglutination tests.

Other Surfaces

Surfaces other than athletic playing surfaces were tested for the presence of microbes and *S. aureus*. These surfaces are not granulated and thus the results are listed in Table 2 as total colony number as opposed to CFU per gram of granulated material.

Table 2. Number of colonies per swab detected on R2A media from various sources in public spaces and an athletic training facility.

Source	Colony number
Public areas	
Computer mouse	>600
Elevator button	155
Outside door handle	80
Computer keyboard	33
Athletic training facility	
Cold pool	24
Blocking pads*	130
Sauna	536
Football*	142
Weight equipment 1*	62
Weight equipment 2*	414
Towel hamper	103
Stretching table	14
Used towels*	29
Trash can for drink cups	205

*Sampled immediately after use

Table 3. Surfaces that tested positive (+) for *S. aureus* colonies per swab detected.

Source	Colony number
Public areas	
Human hands	+
Human faces	+
Computer mouse	-
Elevator button	-
Outside door handle	-
Computer keyboard	-
Athletic training facility	
Natural turfgrass playing field	-
Synthetic turf playing field	-
Cold pool	-
Blocking pads*	+
Sauna	-
Football*	-
Weight equipment 1*	+
Weight equipment 2*	+
Towel hamper	-
Stretching table	+
Used towels*	+
Trash can for drink cups	-

*Sampled immediately after use

Microbial colonies isolated from surfaces included a mixture of fungi and bacteria. Colonies from the trash can were predominantly fungi. While not specifically identified, all colonies from the sauna swab appeared to be the same. *S. aureus* was positively identified from several samples including towels, blocking pads, weight equipment, and the stretching table. In addition, *S. aureus* was positively identified from every facial and hand swabs done.

Discussion

Considering the data in Table 1, the number of total colonies detected varied considerably between sites. In most cases, the number of total microbes at a given site was similar for both high use and low use areas of the field. In general, indoor fields tended to have lower overall microbial populations (0-7267 CFU) than outdoor fields. At one facility where indoor and outdoor fields were sampled on the same day, the indoor fields contained 0-67 CFU/g crumb rubber, while the outdoor field contained 2.8-3.3x10^4 CFU/g crumb rubber. While indoor fields represent only 20% of the fields sampled in this study a consistent trend is apparent.

Total microbial populations for the two natural turf athletic fields were an order of magnitude higher than populations for the infill systems with the highest numbers. Also, observationally, there appeared to be a greater diversity in the types of organisms isolated from soil samples than crumb rubber samples. However, no specific determinations of any cultures were made other than to positively or negatively identify *S. aureus*.

One factor that may influence total microbial populations of infill surfaces is use. Of the 11 fields with at least one subsample having greater than 1x10^4 CFU/g crumb rubber, one of those fields had been heavily used within 7 days of sampling and two fields had been used within 24 hours of sampling. Tracking microbial population fluctuations of a field over time may be of interest.

It is perhaps not surprising that no *S. aureus* colonies were found on any fields, given that the temperature range for growth of *S. aureus* is 7-48°C, with the optimal temperature for growth being 37°C (Baird-Parker, 1990). Surface temperatures of infill surfaces outdoors often exceed the temperature range of *S. aureus* (McNitt, 2005). However, high surface temperatures do not explain the relatively low numbers of total microbes on indoor playing surfaces. These low numbers may, in part, be explained by the permanently very low moisture content of indoor infilled surfaces.

In conclusion, there are generally lower numbers of total microbes present in the infill or fibers of the synthetic turf systems tested compared to natural turfgrass rootzones and *Staphylococcus aureus* bacterium were not found on any of the playing surfaces. *Staphylococcus aureus* bacterium were found on towels and other devices used to train athletes.

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AN ASSESSMENT OF CHEMICAL LEACHING, RELEASES TO AIR AND TEMPERATURE AT CRUMB-RUBBER INFILLED SYNTHETIC TURF FIELDS

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Preface

From the Spring of 2008 to the Fall of 2008, the New York State Department of Environmental Conservation conducted a series of studies to assess some potential impacts from the use of crumb rubber as infill material in synthetic turf fields. Crumb rubber samples were obtained from New York State manufacturers and evaluated to determine the potential for release of pollutants into the air and by leaching. Field sampling was conducted at two New York City fields to evaluate the release of airborne chemicals, release of particulate matter and measurements of heat. Ground and surface water was evaluated at other fields to assess potential impacts. The New York State Department of Health assessed the air quality monitoring survey data. This report addresses some aspects of the use of crumb rubber infill in synthetic turf fields and is not intended to broadly address all synthetic turf issues, including the potential public health implications associated with the presence of lead-based pigments in synthetic turf fibers. Information about lead in synthetic turf fibers is available in a Centers for Disease Control and Prevention Health Advisory available at http://www2a.cdc.gov/han/archivesys/ViewMsgV.asp?AlertNum=00275.

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Executive Summary

This report presents the findings from a New York State Department of Environmental Conservation (NYSDEC) study, designed to assess potential environmental and public health impacts from the use of crumb rubber as infill material in synthetic turf fields. The New York State Department of Health (NYSDOH) evaluated the potential public health risks associated with the air sampling results. The study focused on three areas of concern: the release and potential environmental impacts of chemicals into surface water and groundwater; the release and potential public health impacts of chemicals from the surface of the fields to the air; and elevated surface temperatures and indicators of the potential for heat-related illness ("heat stress") at synthetic turf fields.

The study included a laboratory evaluation, applied to four types of tire-derived crumb rubber (car, truck, a mixture of car and truck, and a mixture cryogenically produced), to assess the release of chemicals using the simulated precipitation leaching procedure (SPLP). The results of this evaluation indicate a potential for release of zinc, aniline, phenol, and benzothiazole. Zinc (solely from truck tires), aniline, and phenol have the potential to be released above groundwater standards or guidance values. No standard or guidance value exists for benzothiazole. However, as leachate moves through soil to the groundwater table, contaminant concentrations are attenuated by adsorption and degradation, and further reduced by dilution when contaminants are mixed with groundwater. An analysis of attenuation and dilution mechanisms and the associated reduction factors indicates that crumb rubber may be used as an infill without significant impact on groundwater quality, assuming the limitations of mechanisms, such as separation distance to groundwater table, are addressed.

Analysis of crumb rubber samples digested in acid revealed that the lead concentration in the crumb rubber samples were well below the federal hazard standard for lead in soil and indicate that the crumb rubber from which the samples were obtained would not be a significant source of lead exposure if used as infill material in synthetic

turf fields. The evaluation of volatile and semi-volatile organic compounds by off-gassing proved difficult to conduct quantitatively due to the strong absorptive nature of the crumb rubber samples but the results did provide useful information for additional analytes in the ambient air field investigation.

A risk assessment for aquatic life protection performed using the laboratory SPLP results, found that crumb rubber derived entirely from truck tires may have an impact on aquatic life due to the release of zinc. For the three other types of crumb rubber, aquatic toxicity was found to be unlikely. When the results of the column tests are used in this risk assessment model, no adverse impacts are predicted for any of the crumb rubber types evaluated. Although the SPLP results predict a greater release of chemicals, the column test is considered more representative of the field conditions.

The study also included a field sampling component for potential surface and groundwater impacts. This work has not been fully completed at the time of this report. The groundwater sampling that was conducted shows no impact on groundwater quality due to crumb rubber related compounds, but this finding should not be considered as conclusive due to the limited amount of data available. Additional sampling of surface and groundwater at crumb-rubber infill synthetic turf fields will be conducted by NYSDEC. The results will be summarized in a separate report.

A field evaluation of chemical releases from synthetic turf surfaces was conducted at two locations using an air sampling method that allowed for identification of low concentration analytes and involved the evaluation of the potential releases of analytes not previously reported. Few detected analytes were found. Many of the analytes detected (e.g., benzene, 1,2,4-trimethylbenzene, ethyl benzene, carbon tetrachloride) are commonly found in an urban environment. A number of analytes found in previous studies evaluating crumb rubber were detected at low concentrations (e.g., 4-methyl-2-pentanone, benzothiazole, alkane chains (C4-C11)).

A public health evaluation was conducted on the results from the ambient air sampling and concluded that the measured levels of chemicals in air at the Thomas Jefferson and John Mullaly Fields do not raise a concern for non-cancer or cancer health effects for people who use or visit the fields.

The ambient air particulate matter sampling did not reveal meaningful differences in concentrations measured on the field and those measured upwind of the field. This may be explained by the lack of rubber dust found in the smaller size fraction (respirable range) through the application of aggressive sampling methods on the surface of the fields. Overall, the findings do not indicate that these fields are a significant source of exposure to respirable particulate matter.

The results of the temperature survey show significantly higher surface temperatures for synthetic turf fields as compared to the measurements obtained on nearby grass and sand surfaces. While the temperature survey found little difference for the indicators of heat stress between the synthetic turf, grass, and sand surfaces, on any given day a small difference in the heat stress indicators could result in a different guidance for the different surface types. Although little difference between indicators of heat stress measurements was found, the synthetic turf surface temperatures were much higher and prolonged contact with the hotter surfaces may have the potential to create discomfort, cause thermal injury and contribute to heat-related illnesses. Awareness of the potential for heat illness and how to recognize and prevent heat illness needs to be raised among users and managers of athletic fields, athletic staff, coaches and parents.

This assessment of certain aspects of crumb-rubber infilled synthetic turf fields was designed to collect data under conditions representative of “worst case” conditions (e.g., summer-time temperatures that should maximize off-gassing of chemicals). However, samples collected under different conditions, using different methods or at different fields could yield different results. For example, the results of measurements may be different for fields of other ages or designs (e.g., different volumes of crumb rubber infill, non-crumb rubber infill) or for indoor fields. This report is not intended to

broadly address all synthetic turf issues, including the potential public health implications associated with the presence of lead-based pigments in synthetic turf fibers. Information about lead in synthetic turf fibers is available in a Centers for Disease Control and Prevention Health Advisory available at
http://www2a.cdc.gov/han/archivesys/ViewMsgV.asp?AlertNum=00275

1. Introduction

Background

Crumb rubber, also referred to as ground rubber, is finely ground rubber derived from recycled or scrap tires. Over 20 million scrap tires are generated annually in New York State (NYS). The R.W. Beck consulting firm estimated that in 2004, about 22.5 percent of NYS generated scrap tires were used to produce ground rubber (Beck 2006). Ground rubber and ground rubber products derived from scrap tires have a wide range of customers, both inside and outside NYS, including: molded product producers, schools, sports stadiums, landscape firms, road construction firms and new tire manufacturers. Growth in ground rubber production is largely centered on its use in mulch products, playground materials, and sports field markets. Crumb rubber is a common infill material for synthetic turf fields providing cushion and ballast for the playing surface. The benefits claimed for choosing crumb rubber over natural grass fields include reduced water needs and maintenance, avoided need for pesticides, herbicides or fertilizer, reduced injuries, and an "all-weather" playing surface. Out of the 850 synthetic turf fields in the United States, NYS has about 150 fields (Katz 2007).

Governmental agencies in Norway, New York City and California have conducted evaluations of the potential health issues associated with the use of crumb rubber as infill at playgrounds and synthetic turf fields. Their assessments did not find a public health threat (NIPHRH 2006, NYCDOHMH 2008b, CIWMB 2007). However, several recent preliminary studies by Zhang et al. (2008), Mattina et al. (2008) and RAMP (2007) indicated the presence of organic compounds, such as polycyclic aromatic hydrocarbons and heavy metals, such as zinc, and raise concerns that these substances could have potential adverse impacts on the environment and public health, especially for children playing on these synthetic turf fields for extended time periods. Additionally, studies have reported high surface temperatures on synthetic turf fields and raised concern about potential heat-related illness ("heat stress") during play (DeVitt et al. 2007, Williams and Pulley 2006).

Under New York State Environmental Conservation Law, § 27-1901 (ECL), crumb rubber is not considered a solid waste and therefore its use is not regulated as a

solid waste under the NYSDEC solid waste regulations or the ECL. However, in response to public concerns about the safety of crumb rubber used at synthetic turf fields, the NYSDEC initiated a study to assess the potential environmental and health impacts from the use of crumb rubber as an infill material in synthetic turf fields.

NYSDEC completed a study protocol in the spring of 2008 (NYSDEC 2008). The protocol included both laboratory evaluations and field sampling components. The objective was to collect data to assess potential impact to both surface and ground waters due to leaching of chemicals, assess potential public health impact from air release of chemicals and evaluate surface temperature and indicators of heat stress.

The laboratory evaluations began in the late spring. The field sampling components began in the summer at two fields in New York City. A field in the Bronx at the John Mullay Park was selected since the field had been installed less than a year at the time of sampling. The second field sampled was in Manhattan at Thomas Jefferson Park and the synthetic turf was approximately 4 years old at the time of sampling. Two different fields were selected to potentially provide information on whether contaminant releases would differ relative to the age of the field.

Upon collection of the laboratory data from the surface water and groundwater assessment, NYSDEC staff evaluated potential environmental and aquatic life impacts. Upon collection of the laboratory data from the ambient air monitoring survey, NYSDOH staff evaluated potential public health impacts.

Synthetic turf composition

Crumb rubber is finely ground rubber manufactured from scrap tires with a size typically of about 1/16 inch (about 2-3 mm) and one of its current uses is as infill material at synthetic turf fields. The infill material consists of either all crumb rubber or a mix of coarse sand and crumb rubber. The infill is brushed into the artificial grass fibers to keep the fibers upright and to cushion and provide ballast to the playing surface.

Figure 1.1 depicts a typical cross section of a synthetic turf field. Although specific field construction varies, most new fields are generally comprised of three layers and use crumb rubber as infill material. The top layer usually consists of nylon or polyethylene fibers attached to a polypropylene or polyester plastic woven fabric

backing. The fabric backing supports the infill material and has holes for drainage of water. The infill material, between the fibers typically is either crumb rubber, flexible plastic pellets, sand, rubber-coated sand or a combination of sand and crumb rubber. Below the woven fabric backing is a layer of crushed stone with plastic tubing for drainage and rubber padding for shock absorbance. The final layer is commonly comprised of a permeable fabric placed over a stable soil foundation.

If the application rate of crumb rubber is approximately two to three pounds per square foot (NYSDOH 2008), for a typical sport field of 230 by 360 feet, about 83 to 120 tons of crumb rubber are used. Assuming 48 inches annual rainfall (NRCC 2000), the average runoff flow rate across the entire turf field is about 7,000 gallons per day.

Laboratory evaluation

The objectives of this portion of the study were to evaluate leaching and air releases of chemicals from randomly selected crumb rubber samples obtained from four scrap tire processing facilities in NYS. The crumb rubber samples were split for each of the laboratory evaluations. Aggressive laboratory testing methods, not necessarily translatable to environmental conditions, were used in this portion of the study to fully evaluate all potential releases of chemicals.

The crumb rubber samples were subjected to two sequential, aggressive leach tests. Another type of test was conducted, intended to simulate acid rain conditions. The crumb samples also were subjected to an acid digestion test to evaluate the lead concentration in the samples.

In addition to evaluating release of chemicals in the water environment, the release of chemicals to the air also was evaluated. In this portion of the study, sometimes called an off-gassing evaluation, crumb rubber samples were evaluated at three different temperature levels to assess chemical releases under a range of environmental temperatures.

The information gathered from these analyses was used to determine the potential parameters of concern for the field evaluation of surface water, groundwater and ambient air. Additionally, these data were used to estimate potential impacts on surface water, groundwater and aquatic life.

Field sampling approach and evaluation of potential environmental and public health impacts

The field sampling portion of the study was comprised of a surface water and groundwater assessment, an air quality survey and a temperature and indicators of heat stress evaluation.

The objectives of the surface water survey were to collect runoff samples from drainage pipes at two synthetic turf fields during rainfall events and to measure the concentration of metals and organic compounds that may leach from the crumb rubber. The objectives of the groundwater survey were to collect samples from down gradient wells at existing synthetic turf fields and to measure the concentration of metals and organic compounds that may leach from the crumb rubber.

The air quality monitoring survey was conducted to determine if organic compounds and particulate matter concentrations above the field surface were different from those found upwind of the fields. An evaluation of the potential health risks from exposure to chemicals found in the air survey was conducted by the NYSDOH. Surface samples were collected to assess particle size and composition and grass samples also were obtained to determine composition.

Finally, a temperature survey, which included measuring surface temperatures and indicators of heat stress above the surface in comparison to a nearby grass and sand surfaces, was performed.

2. Laboratory Analysis of Crumb Rubber Samples

2.1 Objective and Design

The objectives of this portion of the study were to evaluate leaching and air releases of chemicals from randomly selected crumb rubber samples obtained from four scrap tire processing facilities in New York State (NYS). Although crumb rubber generated from these facilities may not necessarily be used at existing turf fields in New York State, it is anticipated that the crumb rubber from these facilities would be representative of crumb rubber generated at out-of-state facilities. Aggressive laboratory testing methods were used in this portion of the study which may overestimate releases from the samples as compared to releases in the ambient setting. The information gathered from these analyses was used to determine potential parameters of concern in the evaluation of the groundwater and ambient air surveys conducted in this study.

The leaching portion of the study evaluated the release of semi-volatile organic compounds (SVOCs), including rubber-related compounds such as benzothiazole, and 23 metals, including arsenic, cadmium, chromium, copper, lead, mercury, vanadium, and zinc, from the crumb rubber under an acid rain conditions. To determine if the release rate changes over time, a second SPLP test on the same sample was performed. The crumb rubber samples also were subjected to an acid digestion test to evaluate the total lead concentration in the samples.

The objective of the air release (off-gassing) portion of the study was to develop a list of analytes to inform the field evaluation portion of the study. Crumb rubber samples were evaluated at three different temperature levels: 25°C (77°F), 47°C (117° F) and 70°C (158°F) to assess a range of environmental temperature conditions. The lower value (25°C) represents a temperature for an indoor field. The center value (47°C) was the average surface temperature recorded in a study conducted at Brigham Young University (Williams and Pulley 2006) for an outdoor field. Finally, 70°C was considered a potential high surface temperature that could be achieved at NYS fields (Willams and Pulley 2006, Fresenburg and Adamson 2005). In addition to identifying rubber related chemicals reported in previous studies, the laboratory also reported the top 20 tentatively identified compounds (TICs).

2.2 Sample Collection

NYS has four crumb-rubber processing facilities and their production rates range from 0.5 million to 10 million pounds of crumb rubber per month. In January 2008, crumb rubber samples were collected (in 500 mL laboratory certified clean glass jars) from the facilities and sent to NYSDEC's contract laboratory for analysis. Table 2.1 provides information on each facility's production rate, sample type, and number of samples obtained from that facility. Crumb rubber is derived from truck and passenger car tires and is produced by both ambient and cryogenic grinding processes. Ambient grinding occurs at room temperature when tire chips are finely ground to desired particle sizes. In the cryogenic grinding process, whole tires first are reduced to tire chips of approximately 3-inch size. These chips are then frozen using liquid nitrogen at -195°C (-319°F). Freezing converts the rubber to a brittle, glassy state in which it is easily shattered into tiny smooth-sided particles and separated from any adhering wire or fabric (Snyder 1998). Facility #1 processes crumb rubber from both truck tires and passenger tires in an ambient grinding process. Crumb rubber is derived from whole tires and separated by type (truck versus passenger car) at this facility. Facility #2 also applies an ambient grinding process for whole tires, but mixes the truck and passenger car tires together with a greater proportion coming from car tires. Facilities #3 and #4 produce crumb rubber from a mixture of car and truck tire chips (the tires are preprocessed into chips approximately 2-3 inches long prior to grinding). Facility #3 uses an ambient grinding process, while Facility #4 applies a cryogenic process.

Thirty-one samples of crumb rubber were randomly collected. One of the samples was split for quality control purposes for a total of 32 samples. The samples were split and sent to NYSDEC's contract laboratory for the leaching and off-gassing analysis.

Information about each sample, including the processing facility and crumb rubber type, was recorded and each sample was assigned a unique identification code.

2.3 Laboratory

The samples were shipped to NYSDEC's contract laboratory, Columbia Analytical Services, which is certified by the NYSDOH Environmental Laboratory Approval Program (ELAP).

2.4 Laboratory Leaching Test

2.4.1 Test Methods and Test Parameters

EPA SW-846 Method 1312 (USEPA 2009), the Synthetic Precipitation Leaching Procedure (SPLP) test, was used to evaluate the leaching potential of the crumb rubber samples. The analysis involves the mixing of 100 grams of crumb rubber in two liters of water at pH 4.2 to simulate acidic rainwater. The mixture is then rotated for 18 hours. After the agitation period, the leachate is filtered and analyzed for semi-volatile organics (SVOCs) and 23 metals. To determine if the release rate changes over time, a second SPLP test on the same sample was performed.

EPA SW-846 Method 6010B (USEPA 1996a), an acid digestion method used to determine metals in ground waters and solid materials, was used to evaluate the lead content in the crumb rubber samples.

2.4.2 Data Review

All data received from the laboratory were subjected to a comprehensive review for data completeness and compliance following the criteria in the USEPA's Contract Laboratory Program National Functional Guidelines for inorganic (USEPA 2004) and organic (USEPA 1999a) data review. The review for these data indicates the data are useable for the purpose of this study which is to develop a list of chemicals for analysis in the field portion of the study. Appendix A1 reports the results of this review conducted by NYSDEC's Chemistry and Laboratory Services Section.

2.4.3 Test Results

Appendix A2 provides the laboratory leaching test results. Tables 2.2 and 2.3 present a summary of the results for metals and SVOCs, respectively. These tables have been arranged by the frequency that the analytes were detected in the samples. As shown

in Table 2.2, three metals were detected above the Groundwater Standard (NYSDEC 1999). Zinc was the only metal that leached from crumb rubber for every sample tested, with an average concentration close to the groundwater standard. Iron and copper were detected above the groundwater standard in a small percentage of the samples, primarily from crumb rubber derived from truck tires. The remaining analytes detected were below the groundwater standard. Manganese and barium were detected at low concentrations with barium being detected in a low percentage of the samples (19.4%). Lead was detected at half the groundwater standard in a low percentage of the samples, primarily derived from truck tires. Table 2.2 also includes metals that were not detected in the SPLP leachate, along with detection limits.

Figure 2.1 depicts the concentration of zinc in the leachate separated by facility and crumb rubber type. Crumb rubber from truck tires at Facility #1 produced the highest concentration of zinc in the leachate (approximately three times higher than the groundwater zinc guidance value (NYSDEC 1998a). A substantial reduction in zinc leachate concentration is noted for the subsequent SPLP test on these samples. In contrast, the subsequent SPLP tests conducted on the crumb rubber for Facilities #2 and #3 resulted in minimal change in zinc concentration. Finally, the results for Facility #4 (cryogenically produced crumb rubber), show a slight increase in zinc concentration as compared to the first SPLP test. In summary, this figure illustrates that the release of zinc is not uniform and is highly dependent on the type of crumb rubber.

Table 2.3 summarizes the SPLP test results for SVOC analysis. Fifteen SVOCs were detected in the SPLP leachate. Aniline had the highest concentration of the detected compounds and was detected in all samples (for both SPLP passes). For the first SPLP pass, the average concentration of aniline is approximately 20 times higher than the groundwater standard and the subsequent SPLP pass also was above the groundwater standard. Phenol, detected in all samples (for both SPLP passes) was detected at an average concentration 13 times the groundwater standard. The second pass was slightly above the groundwater standard. 4-Methylphenol (detected 94% in the first SPLP and 48% in the second SPLP) had an average concentration marginally above the standard. The combined concentration for all phenols is approximately 18 times higher than the groundwater standard. The remaining analytes were detected infrequently, but found at

concentrations less than the corresponding groundwater standard or there is no groundwater standard available. Therefore, the potential impact of these analytes would be considered insignificant. In summary, the SPLP leach tests report results for aniline and phenol above the groundwater standard and should be considered for further review in the surface and groundwater portion of this study.

Figure 2.2 provides more detail on the levels of aniline found in the different types of crumb rubber. The results for crumb rubber from truck tires were 40 times the groundwater standard. All other types of crumb rubber had lower aniline levels, but well above the groundwater standard of 5 μg/L.

Figure 2.3 displays phenol concentrations for the different types of crumb rubber. It is interesting to note that crumb rubber from truck tires has the lowest phenol concentration, while the cryogenic crumb generated the highest phenol concentration in the leachate – approximately 20 times the groundwater standard. All types of crumb rubber had phenol levels exceeding the groundwater standard of 1 μg /L.

In addition to the above detected SVOCs, Table 2.4 lists the highest detected TICs found in the leachate. Since the instrument was not calibrated for these compounds, the TIC results have been reported as estimated concentrations.

Previous studies report benzothiazole is commonly found in crumb rubber and this was found to be the most prominent compound in the TIC list. Figure 2.4 displays the estimated concentration of benzothiazole in the SPLP leachate for the different types of crumb rubber. Crumb rubber made from truck tires had the highest leaching results for benzothiazole. Benzothiazole and the remaining TICs are further examined in Section 3 (Laboratory Column Test) where the study design more closely resembles ambient conditions.

The lead results from the acid digestion test can be found in Appendix A3. The lead concentrations range from 5.6 – 116 ppm with an average of 30.8 ppm. In the absence of an applicable lead standard for crumb rubber, a comparison of the results to the USEPA hazard standard for lead in bare residential soil (400ppm) (USEPA 2001) was conducted. All results were below the hazard standard of 400 ppm.

2.4.4 Conclusions

Based on this test method aniline, phenol and zinc (for samples derived solely from truck tires) were found above groundwater standards or guidance values. It is important to consider that this test method may result in an overestimate of the release of pollutants under actual field conditions. Additionally, the results indicate that the leaching potential is dependent on the type of crumb rubber, with truck tires typically having the highest leaching potential. The results obtained in the leaching analysis and from the column testing (Section 3) were used to develop a list of analytes for the surface and groundwater portion of the study.

The lead concentration in the crumb rubber samples are below the USEPA hazard standard for lead in bare residential soil and below applicable standards that have been used by others evaluating lead concentrations on synthetic turf fields (NYCDOHMH, 2008a). These data indicate that these samples of crumb rubber would not be a significant source of lead exposure if used as infill material in synthetic turf fields.

2.4.5 Limitations

The leaching method provided a conservative scenario for the following reasons: 1) the method pH 4.2 is slightly lower (more acidic) than the pH of rain water recorded in New York State which runs from 4.35 to 4.76 (NYSDEC 2006); and 2) the method includes 18 hours of agitation, while in practice, crumb rubber is tightly packed as an infill and not agitated as aggressively. Therefore, the method may overestimate the release of compounds of interest. This method, however, will be useful to compare the release rates for different types of crumb rubber under a controlled laboratory setting. Additionally, it provides data for a conservative scenario evaluation for potential surface and groundwater impacts.

It is unknown whether synthetic turf fields in New York State were installed with crumb rubber obtained from production facilities in the State.

2.5 Laboratory Off-gassing Test

2.5.1 Test Methods and Parameters

Upon receipt of the samples for the off-gassing analysis, the laboratory split two different samples for additional quality control evaluation. The crumb rubber samples were heated for 50 minutes to three different temperatures. A modified TO-15 method was used to evaluate VOC and SVOCs released from the samples. A modification was necessary due to the high sorbent properties of crumb rubber. When internal standards were applied to the crumb rubber off-gasses, they were irreversibly adsorbed onto the crumb rubber matrix. Therefore, an external standard technique was used and response factors with units of area counts per nanogram were used for all calibration curves. Additionally, to prevent the off-gasses from contaminating the analytical system, 0.1 gram samples were analyzed yielding a dilution factor of 10, thereby raising the practical quantitation limit from 5.5 to 55 μg/kg.

2.5.2 Data Review

The laboratory was not provided any information regarding the type of crumb rubber in the samples. Field and laboratory, split samples were compared and combined (by averaging) if both samples yielded results. If one of the split samples was found as a non-detect and the other sample was reported as an estimated value, the second sample was consider as a non-detect to allow for the combining of the split samples.

A quality control/quality analysis review of the laboratory results for the samples evaluated at the three temperature levels was conducted by staff in NYSDEC's Chemistry and Laboratory Services Section. The review and comments are provided in Appendix A4 (samples at 25°C and 47°C) and Appendix A5 (samples at 70°C). A recommendation was made by the reviewing chemist to treat all results qualitatively. It was noted by the chemist that the surrogate recoveries were low due to the high adsorptivity that the crumb rubber has for VOCs. Therefore, it was recommended that all analytical results from the off-gassing experiments be regarded as estimated quantities, in the correct proportions.

2.5.3 Test Results

The number of analytes detected increased with increasing temperatures. At 25°C, 47°C and 70°C, the number of compounds detected was 47, 54, and 60,

respectively. The full list of analytes detected by temperature and subdivided by crumb rubber type can be found in Appendix A6.

The laboratory off-gassing data provided information on analytes detected and relative concentrations to allow development of a list of additional analytes for the ambient air survey portion of the study. Unknown compounds and mixed isomers were not considered for evaluation in the ambient air field sampling evaluation. Analytes which were detected in at least 50% of the samples for each crumb rubber type (i.e., car, truck, mixture of car and truck, and cryogenic) were selected. From this subset, analytes were selected for consideration if they were detected in more than 50% of all the samples collected. A total of 18 analytes were identified for further consideration. Analytes that were already proposed for evaluation by the laboratory evaluating the ambient air field samples have not been included in this total count. Additional criteria were applied as detailed in a memo attached as Appendix A7 and a final list of analytes was developed and submitted to the laboratory that conducted the analysis of the ambient air survey samples.

2.5.4 Conclusions

Although the laboratory off-gassing portion of the study proved difficult to conduct quantitatively due to the strong absorptive nature of the crumb rubber samples for VOCs, the results did provide useful information for additional analytes to be included in the laboratory analysis of the ambient air field samples. Five additional analytes were selected for inclusion in the ambient air survey, based on the results of the crumb rubber off-gassing study. Three analytes were selected for inclusion in the air survey because of high toxicity (i.e., low reference concentration): aniline (CAS# 62-53-3), 1,2,3-trimethylbenzene (526-73-8), and 1-methylnaphthalene (90-12-0). Two analytes were selected because of high frequency of detects and high relative concentrations found in the off-gassing study: benzothiazole (95-16-9), and tert-butylamine (75-64-9). Finally, it is uncertain what effect the absorptive nature of the crumb rubber, as noted in the laboratory setting, may have in the field setting.

2.5.5 Limitations

The strong absorptive nature of the crumb rubber samples prevented a quantitative analysis of the results in this portion of the study. Additionally, laboratory conditions do not mimic the environmental setting. Other factors such as compression and degradation of the crumb rubber during field use and changes attributable to solar radiation may affect the release of chemicals in the ambient environment.

It is unknown whether synthetic turf fields in New York State were installed with crumb rubber obtained from production facilities in the State.

3. Laboratory Column Test

3.1 Objective and Design

The objectives were to evaluate the leaching potential of crumb rubber using a laboratory method that more closely represents field conditions than the SPLP test and to compare the results with the more aggressive SPLP tests described in Section 2. The test simulates the release of chemicals from crumb rubber by exposing the crumb to synthetic rainwater in a column designed to closely mimic ambient conditions at synthetic turf fields. The crumb rubber was exposed to an equivalent of one year's rainfall in NYS (48 inches (NRCC 2000)) using simulated rainwater at pH 4.2, which is slightly more acidic than the low end of the pH range found in NYS (4.35 to 4.76). The selection of pH 4.2, which is equal to the pH of the SPLP test, will facilitate the comparison between the results of the column test and SPLP test. The simulated rainfall that passed through the tire crumb columns, without being agitated as in the SPLP test, was collected at 12 inch rainfall intervals. Two types of crumb rubber were selected for the leaching experiment, a truck tire crumb (Facility #1) and a cryogenically prepared mixed crumb (Facility #4) because the SPLP leaching analysis indicated that more analytes and higher relative proportions were released from these types of crumb rubber. The laboratory column test was conducted by staff in NYSDEC's Division of Solid and Hazardous Materials laboratory. The resultant leachate was sent to NYSDEC's contract laboratory with ELAP certification for this analysis.

3.2 Equipment

The column system was designed by staff at NYSDEC. The pump system was a Cole Palmer System, consisting of Master Flex L/S Computerized Drive (P/N 7550-50), with 7519-16 4 roller pumphead. The pumphead drove 7519-80 peristaltic cartridges, up to eight cartridges could be run off of one pumphead. The system was interfaced (RS-232) to a Dell GX280 PC running MasterFlex WinLin Linkable Instrument Networking Software (V2.0) for instrument control. The peristaltic tubing used was Masterflex silicone platinum tubing, L/S-14. The silicone tubing was run from the simulated rainfall reservoir and passed through the peristaltic pump cartridges. The silicone tubing was

then connected to 1/8 inch OD Teflon tubing using an Upchurch P-798 conical adapter. From that point, 1/8 inch OD Teflon tubing was used to connect to the chromatography columns, and from the chromatography columns to the collection bottles.

The chromatography columns were Kontes P/N 820830-1520 Chromaflex Glass Columns – 4.8 cm ID x 15 cm L. An adjustable bed support (P/N 420836-0040) was used to provide minimal (2.2 inch gravity packed to 2.0 inch compressed) bed compression of the tire crumb to maintain reproducible elution conditions. The bed supports utilized a 20 micron polyethylene screens and Teflon/propylene seals.

3.3 Reagents

Table 3.1 reports the reagents used and supplier. The production of rainwater (Serkiz et al. 1999) was modified through the use of an acetic acid/acetate buffer system (0.0003M) adjusted to pH 4.2 with 0.5M HNO_3/H_2SO_4 to simulate an aggressive acid rain scenario. Final pH determinations were made using a Thermo Orion 920A+ pH meter with an Orion Ross Ultra combination pH electrode. For the final determination of pH, the simulated rainfall solution was allowed to equilibrate with the electrode overnight, in a covered beaker. The pH of the simulated rainfall solution was checked at the end of the leachate study and found to be stable.

3.4 Column Test Procedures

Crumb rubber was gravity packed into a glass chromatography column to a depth of approximately 2.2 inches. The amount of crumb used to pack the column was weighed for each column preparation. To ensure even flow of the eluent throughout the crumb bed, and to aid in consistency, the crumb column was compressed to 2.0 inches using the adjustable bed support. Following preparation of the column, the crumb was then eluted with simulated rainfall in an intermittent manner, with flow through the columns for half an hour, followed by no flow for half an hour, with the sequence maintained until the equivalent of 12 inches of rain passed through the crumb. The nominal flow through the column was 2 mL/min, with the equivalent of 12 inches of rain being passed through the column in a total of 300 minutes of flow time, or 600 minutes of total run time. The simulated rainfall eluent was collected in tared 1 liter I-Chem Series

300 bottles held in an ice/water bath. To minimize potential effects from atmospheric cross contamination, the collection bath was covered during the time of eluent collection. At the end of the collection of the simulated 12 inch of rainfall, the bottles were removed from the ice bath, dried, and then weighed to determine the total volume of eluent passed through the crumb. A portion (about 30 mL) of the eluent was then placed into a nitric acid preserved bottle for total zinc analysis, both bottles were sealed, and shipped on ice to the laboratory for analysis using next day courier. The column then sat for approximately 14 hours, before the crumb was subjected to a fresh elution sequence.

Two types of crumb rubber were selected for the leaching experiment, a truck tire crumb (Facility #1) and a cryogenically prepared mixed crumb (Facility #4). Each of the crumb rubber samples subjected to the elution experiment was run in triplicate over 4 days, for a total of 24 samples sent for analysis. In addition, a blank column was prepared and run with each sample set consisting of an identical column set-up without tire crumb added to the column. This provided a method of assessing any potential for contamination that might have occurred during the leaching experiment. Calibration of the column flow rates and peristaltic pump cartridges was done by passing ASTM type I water through the columns using the flow program for 5 days prior to the experiment. The empty column set-ups were then equilibrated with pH 4.2 simulated rainwater for three days prior to the start of the experiment, also checking on flow calibration. At the beginning of the experiment, the calibrated, flushed, and equilibrated columns were packed with the tire crumb samples, and the experiment started with immediate collection of eluent, thus mimicking field events following placement of the tire crumb.

3.5 Eluent Analysis - Test Method and Test Parameters

The eluent samples were analyzed for total zinc by SW-846 Method 6010, and selected SVOCs by SW-846 Method 8270C (USEPA 2009). The laboratory instrumentation was calibrated, using reference standard materials, for selected SVOCs listed in Table 3.2.

3.6 Data Review

Appendix B1 includes the data review summary conducted by NYSDEC's Chemistry and Laboratory Services Section for the column test results. Overall, the data are usable though some of the results must be considered as estimated due to Quality Control deficiencies.

3.7 Test Results

Appendix B2 contains the laboratory column test results. Table 3.3 summarizes the results for zinc and detected SVOCs only. The average concentrations are compared with the NYS Groundwater Quality Standards (NYSDEC 1998b). As illustrated in Table 3.3, aniline was found at the highest concentration relative to the standard, found at more than five times the groundwater standard.

Figures 3.1, 3.2 and 3.3 display a comparison of zinc, aniline, and phenol concentrations, respectively, between the SPLP and the column tests for two types of crumb rubber. The concentrations of these analytes in the column tests are measured after 12, 24, 36, and 48 inches of simulated rainfall. As expected, these concentrations are all lower than the ones in the SPLP tests, but at different ratios. For example, as noted in Figure 3.1, the average zinc concentration in the leachate of the truck crumb for the column test is approximately 16 times lower than the SPLP test concentration. In comparison, for the cryogenic crumb zinc is only three times lower in concentration. The zinc leachate concentration is well below the groundwater guidance value. Figure 3.2 indicates the average aniline concentration of the truck crumb in the column test is approximately six times lower than the SPLP test concentration. In comparison, for the cryogenic crumb aniline is five times lower in concentration. The aniline leachate concentration is above the groundwater standard. In Figure 3.3, it is noted that the average phenol concentration of the truck crumb in the column test is approximately eight times lower than the SPLP test concentration, while the cryogenic crumb is 16 times lower in concentration.

3.8 Conclusions

The column test procedure is considered more representative of field conditions and as expected, the concentration of all chemicals of concern was lower than that of the

SPLP for the two types of crumb rubber evaluated. Phenol and aniline leachate results were above the groundwater standards and these analytes will be included in the surface water and groundwater evaluation.

3.9 Limitations

Although the laboratory column test was more representative of actual ambient field conditions as compared to the SPLP analysis, observations noted by the chemist conducting the laboratory column test indicate that some variability may exist in the data results due to limitations such as flow channeling and clogging of the effluent.

4. Water Quality Survey at Existing Turf Fields

4.1 Surface Water Survey

4.1.1 Objectives and Design

The objectives of surface water survey were to collect runoff samples from drainage pipes at existing turf fields during rainfall events and to measure the concentration of metals and organic compounds that may be present in the runoff. The concentrations of these compounds were compared with the NYS Water Quality Standards Surface Waters and Groundwater (NYSDEC 1999).

The original study design called for sampling two synthetic turf fields selected for the overall study design. After a few rainfall events in August and September 2008, no samples were collected at these fields, due to problems such as clogging and insufficient runoff volume in the drainage collection pipes. Therefore, another field (installed in 2007) was identified where the drainage pipes were easily accessible and sufficient volume of surface runoff could be collected. Staff were able to collect only one surface runoff sample from this site before the water sampling effort was halted due to NYSDEC budget restrictions.

4.1.2 Test Methods and Test Parameters

Test parameters include volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs) and metals using Methods 624, 625, and 200.7. The NYSDEC contract laboratory H2M Labs, Inc. conducted the analysis. The laboratory holds an ELAP certification for these methods. The analysis of this sample did not include chemicals related to crumb rubber, such as aniline and benzothiazole. Future sampling activities and subsequent analysis will include the crumb rubber related compounds.

4.1.3 Data Review

Appendix C1 includes data review findings for the surface runoff test results, which indicates the data are usable.

4.1.4 Test Results

Tables 4.1, 4.2, and 4.3 include test results for the surface runoff sample. These results show no organics were detected. Since all results for the organics were below detection limits, a comparison to surface water standards was not conducted. For metals, zinc was detected at 59.5 μg/L which is below the surface water standard. Several other metals also were detected (chromium, copper, lead, nickel) but at concentrations below the surface water standards. Appendix C2 provides the laboratory results.

4.2 Groundwater Survey

4.2.1 Objectives and Design

The objectives of the groundwater survey were to collect samples from downgradient wells at existing synthetic turf fields and to measure the concentrations of SVOCs that may leach from the crumb rubber. The concentrations of these compounds were compared to the NYS Groundwater Quality Standards (NYSDEC 1998b). To obtain samples in a timely manner, the survey focused on areas where sandy soil is predominant. In 2008, four turf fields were selected ranging from ≤1 - 7 years old. Table 4.4 provides the field characteristics. Two to three downgradient wells were installed at each field and samples were collected at various depths by staff from the Suffolk County Department of Health Services (SCDOHS). The samples were sent to the NYSDEC contract laboratory. The thirty-two groundwater samples at these sites have a depth to the groundwater table ranging from 8.3 ft to 70 ft as shown in Table 4.4. NYSDEC will perform additional sampling in 2009 at different sites that have depth to groundwater less than 8.3 ft to further characterize potential groundwater impacts.

4.2.2 Test Methods and Test Parameters

SVOCs, including aniline and benzothiazole were assessed by SW-846 Method 8270C.

4.2.3 Data Review

Appendix C3 includes data review findings for the SVOC groundwater test results, which indicates the data are usable.

4.2.4 Test Results

All test results were below the limit of detection for all groundwater samples analyzed. Table 4.5 reports the detection limits for the specific compounds associated with crumb rubber, aniline, phenol, and benzothiazole. Table 4.6 reports the detection limits for all SVOCs evaluated. A comparison of the results to applicable groundwater standards was not conducted, since all were below the detection limit. Appendix C4 provides the laboratory results.

4.3 Conclusions

Surface water

No organics were detected and several metals were detected at low levels for one sample analyzed. The NYSDEC will perform additional sampling of surface water runoff in 2009. The additional test results will be included in a separate report.

Groundwater

Based on test results of 32 groundwater samples, no organics or zinc were detected at the turf fields. The NYSDEC will perform additional sampling of groundwater at sites with shallower groundwater levels in 2009 to better represent potential impacts and will present test results in a separate report.

4.4 Limitations

Surface water

Results for the surface water quality survey are based on one sample and have very limited application to other fields. Additionally, the initial surface water survey did not include chemicals related to crumb rubber, such as aniline and benzothiazole. The surface water sample was analyzed by a different NYSDEC contract laboratory than the other water samples obtained and evaluated in this study. The laboratory used reported

higher detection limits when compared to the results for the groundwater sample analysis. Future sampling activities will include the crumb rubber related compounds and standardized laboratory analyses.

Groundwater

Although the results from the downgradient wells show no impact on groundwater quality due to crumb rubber related compounds, this finding should not be considered as conclusive, due to limited data available. NYSDEC will perform additional sampling of groundwater at sites having different characteristics, such as shorter separation distance to groundwater table, to further evaluate potential impacts. The additional sampling will also include an expanded list of parameter for analysis.

5. Potential Groundwater Impacts

5.1 Dilution-Attenuation Factor (DAF)

One method to determine the potential for groundwater impacts is through the application of a dilution-attenuation factor (DAF). As leachate moves through soil to the groundwater table, contaminant concentrations are attenuated by adsorption and degradation. After entering the groundwater table, a chemical is mixed with groundwater and the resultant concentration is further diluted. The DAF is used to account for these mechanisms and is often called a correction factor. The higher the DAF, the greater the attenuation needed to achieve the groundwater standard.

The NYSDEC's soil cleanup guidance for hazardous remediation sites was first established in 1992. The DAF is used in guidance for the remediation program, found in the Technical Support Document for NYSDEC's 6 NYCRR Part 375 soil cleanup objectives (NYSDEC and NYSDOH 2006). In developing the soil cleanup objectives, a DAF of 100 was used for organics and 40 for inorganics because experience has shown that when a site is cleaned up using these DAFs, the groundwater quality is protected.

Table 5.1 presents the predicted groundwater concentrations calculated by using the SPLP results for the three most prominent organic compounds: aniline, phenol, and benzothiazole with a DAF of 100, and zinc with a DAF of 40. A conservative approach was taken and a comparison to the 95th percentile of the SPLP test (results reported in Section 2 Laboratory Leaching Test) with the groundwater standards was conducted. This evaluation was limited to the two types of crumb rubber with the greatest leaching potential, truck tires and the cryogenic crumb rubber. As shown in Table 5.1, all predicted groundwater concentrations are lower than groundwater standards or guidance values.

5.2 Conclusions

The dilution-attenuation factor (DAF) from the NYSDEC's soil cleanup program is one method to determine if leachate will impact groundwater. Application of the DAF to the leachate results in this study demonstrates that crumb rubber can be used as an infill without significant impact on groundwater quality.

5.3 Limitations

Use of the DAF 100 for organics is presented in the remediation guidance with a note of caution for situations where the contamination source is close (three to five feet) to the groundwater table. The soil cleanup guidance also assumes one percent organic carbon content of soil when organic pollutants are evaluated. Therefore, for areas where organic carbon content is less than the desired level, such as in sandy soils, care should be taken to ensure that the groundwater quality is protected by a sufficient buffer (separation distance) to the groundwater table. The groundwater survey in a sandy soil area presented in Section 4 indicates that no groundwater impacts at sites where the minimum depth to groundwater is 8.3 feet. NYSDEC will perform additional groundwater sampling with shallower groundwater levels to better document potential impacts and needed buffer zones.

6. Potential Surface Water Impacts

6.1 Surface Water Standards

Table 6.1 lists the surface water standards (NYSDEC 1998b) for four most prominent compounds in crumb rubber from Facility #1 (truck tires) and Facility #4 (mixed tires) and a comparison of these standards to the SPLP and the column test results. As mentioned in Section 3, the results from the column test, much lower than the ones obtained from SPLP tests, are considered more representative of field conditions, because the column test does not involve 18 hours of agitation as included in the SPLP test. A conservative approach was applied by using the upper limits for the SPLP and column test results. Zinc concentrations are higher than the surface water standards. For phenol, the concentrations in the column test are lower than the surface water standards. Both aniline and benzothiazole do not have surface water standards. Comparison of the laboratory leaching results directly to surface water standards does not represent what will happen under field conditions. The actual concentration in the surface water body will be lower due to dilution and attenuation. To determine actual impact on the surface water body, the impact can be modeled mathematically and/or actual quality measurements can be taken.

6.2 Risk Assessment on Aquatic Life

Appendix E1 provides a mathematical assessment of the risks to aquatic life from leachate from crumb rubber, based on the SPLP test results for zinc, aniline and phenol. The risk assessment was conducted by NYSDEC's Division of Fish, Wildlife and Marine Resources and concludes that there may be a potential aquatic life impact due to zinc release from crumb rubber solely derived from truck tires, but an impact is unlikely for the mixed tires.

6.3 Conclusions

A risk assessment for aquatic life protection was performed and found that crumb rubber made derived entirely from truck tires may have an impact on aquatic life based on the impacts that zinc may have on aquatic life pathway. For the crumb rubber made

from mixed tires, the potential impacts are insignificant. However, this assessment is based on the SPLP test results which predict a greater the release of chemicals as compared to the column test which is considered more representative of field conditions. If the results of the column test in Table 6.1 are used in the risk assessment model, no adverse impacts are expected.

6.4 Limitations

The dilution factor used in the assessment of potential surface water impact will depend on site-specific information and it is difficult to assume all potential scenarios. The exposure model describes in Section 6.2 addresses one potential scenario which may not be applicable in all cases. As outlined in Section 4, the NYSDEC will perform additional field testing of surface water quality near crumb-rubber infilled synthetic turf fields.

7. Air Quality Monitoring Survey at Existing Fields

7.1 Objectives and Design

The air quality monitoring survey was conducted to determine if volatile organic compounds (VOC), semi-volatile organic compounds (SVOC), and particulate matter concentrations (PM) above the field surface were different than concentrations measured upwind (intended to represent background air quality) of the fields and if the measured concentrations are of public health concern. A goal of this portion of study was to collect samples on summer days when temperatures were above 80°F and the VOC and SVOC releases would be anticipated to be higher than other times of year. To determine the relevance of particulate matter monitoring, surface wipe and microvacuum sampling was conducted to evaluate the type and size of the smaller particles liberated through aggressive sampling. Synthetic grass samples also were obtained to determine composition. Finally, meteorological data were collected to facilitate comparisons to upwind air samples.

This portion of the survey was conduced on the two synthetic turf fields selected for the overall study. These two fields differ in age which may help identify whether chemical releases differ by age of field.

To measure potentially low chemical concentrations in air, field sample collection methods and laboratory analytical techniques were employed to provide minimum detection limits on the order of nanogram (billionth of a gram) per cubic meter levels. Sampling locations included upwind of the fields as well as in the center and at the downwind edge of fields to examine the horizontal profile of contaminant release concentrations. Samples at the center and downwind edge were collected at three different heights to examine a vertical profile of release. A comparison of the upwind and on-field/downwind sample results provided an indication of chemicals potentially released from the field itself.

7.2 Sample Collection

RTP Environmental Associates, Inc. was awarded the contract to conduct the field sampling. Field sampling involved ambient air sampling, surface wipe sampling, surface

microvacuum sampling, ambient particulate matter monitoring and meteorological monitoring.

The field notes recorded by RTP for the Thomas Jefferson Field, detailing field conditions and equipment setup, have been included in this report as Appendix F1. The field notes recorded by RTP for the John Mullaly Field are included as Appendix F2.

7.2.1 Date Selection

Samples for each field were collected over a two-day time period. The following criteria were developed to assist with the selection of the sampling date: two consecutive days with no precipitation including the day prior to sampling, forecast winds from the same direction for at least 4-6 hours on each day of sampling at light to moderate speeds and forecast day temperature above 80°F. These conditions were assumed to maximize measurable quantities of VOCs and SVOCs released from the fields and allowed for the comparison of upwind to on-field and downwind samples.

On August 21, 2008, RTP made final preparations to perform tests and was given final approval to proceed with testing at the Thomas Jefferson Park field by New York City Department of Parks and Recreation (NYCDPR) representatives. On August 22, 2008, RTP collected samples at the field. On September 1, 2008, RTP made final preparations to perform tests and was given final approval to proceed with testing at the John Mullaly Park field by NYCDPR representatives. On September 2, 2008, RTP collected samples at the field.

7.2.2 VOC and SVOC Sampling

Samples were collected using sorbent sample collection media. The VOC samples were collected using “active” sampling, pumping large volumes of air through the media. Tenax cartridge and Tenax/Anasorb® cartridge in series were used. One-hundred twenty liters of air were drawn through the sampling media over a period of two hours. The SVOC samples were collected using PUF/XAD cartridges and samples were collected over a two hour time period drawing in 4.0 liters per minute. More details on the sampling methods can be found in Appendix F3, RTP’s work plan to perform the ambient air quality monitoring survey.

Figure 7.1 shows the sampling locations for Thomas Jefferson Park and Figure 7.2 shows the sampling locations for John Mullaly Park. These maps also show the location of the wipe, microvacuum and particulate matter monitoring. Nine samples were collected at each field. Table 7.1 reports information on sample location and heights. For quality control and quality assurance purposes, VOC and SVOC field blanks were collected and duplicate samples were obtained at two locations. A lab blank also was analyzed.

For both fields, some modifications to the field sampling protocol were necessary. The SVOC inlets for the field surface samples were placed vertically, approximately 2 mm above the turf surface. The VOC inlets for the field surface samples were placed 1 mm above the turf surface, pointing into the wind. Upwind and downwind edge surface samples were not on the field, and therefore, were placed 1-2 cm above the surface to avoid contact with the soil in these areas.

7.2.3 Wipe Samples

Wipes samples were collected at three locations: on field in the center, on field in shade and at the downwind edge of field, shown in Figures 7.1 and 7.2. For both fields, a duplicate wipe sample was obtained to determine consistency of sampling collection efficiency. Eight samples were submitted to the laboratory for analysis.

Wipe sampling was performed in accordance with the sampling methods outlined in American Society for Testing and Materials (ASTM) E1728 and in the Housing and Urban Development (HUD) guidelines (HUD 1995). Precut templates were used to mark each sampling location and wiping was performed following the HUD guidance. A clean wipe (field blank) was included in the samples sent to the laboratory for analysis. The turf temperature was recorded using an infrared thermometer (recorded by Extech 42510A infrared thermometer) at the time of wipe sample collection.

7.2.4 Microvacuum Samples

Microvacuum samples were collected in accordance with ASTM D 5755-95. Sampling techniques, materials and equipment used followed the HUD guidelines (HUD

1995). Samples were collected in three locations: on field in the center, on field in shade and at the downwind edge of field, shown in Figures 7.1 and 7.2. At one of the locations, a duplicate microvacuum sample was obtained to assess collection efficiency. Seven samples were submitted to the laboratory for evaluation. Samples were collected utilizing 25 mm particulate filter cassettes with a 0.45 μm filter coupled with Buck BioAire sampling pump.

7.2.5 Ambient PM_{10} and $PM_{2.5}$ Monitoring

Particulate matter concentrations were obtained in real-time using a Thermo DataRam (DR) 4000 aerosol monitor with size collectors for $PM_{2.5}$ (particulate matter with an aerodynamic diameter of 2.5 microns (μm) or less) and PM_{10} (particulate matter with an aerodynamic diameter of 10 μm or less). Two Thermo DR-4000 units were used for sampling simultaneously at the upwind location. Samples were collected in four locations: upwind of the field, at the center of field, and at two downwind locations, shown in Figures 7.1 and 7.2. Samples were collected during actual field use. Monitoring was conducted at three feet from the ground and one minute averaged values were recorded for time intervals lasting approximately ten minutes. Prior to field sampling, collocated calibration was conducted with both monitors.

7.2.6 Meteorological Monitoring

On-site meteorological data were collected during the VOC, SVOC and particulate matter sampling. Meteorological parameters measured include wind speed, wind direction, temperature, relative humidity, turbulence and barometric pressure. Data were collected using a Climatronics All-in-One compact weather unit mounted to a ten-foot meteorological tower. Ambient (recorded by Testo 615 temperature meter or weather unit) and surface temperatures (recorded by Extech 42510A infrared thermometer) were also periodically taken at the sampling locations.

7.2.7 Synthetic Grass Sample

During a site visit in July 2008, several blades of the synthetic grass were collected from each field.

7.3 Test Parameters and Methods

7.3.1 Ambient Air Samples

The target list of analytes shown in Appendix F4 was developed based on modifications to the Volatile Organic Sampling Train (VOST) sampling methods 5041A/8260B (USEPA 2009a) and a modified TO-13A (2009b). The laboratory agreed to report the top 20 TICs utilizing surrogates also listed in Appendix F4. TICs are those analytes which were detected but cannot be positively identified or quantified without additional analytical testing. The laboratory also evaluated the presence of five additional analytes identified by the crumb rubber off-gassing study (Section 2). Three analytes were selected for inclusion in the air survey because of high toxicity (i.e., low reference concentration): aniline (CAS# 62-53-3), 1,2,3-trimethylbenzene (526-73-8), and 1-methylnaphthalene (90-12-0). Two analytes were selected because of high frequency of detects and high relative concentrations in the off-gassing study: benzothiazole (95-16-9), and tert-butylamine (75-64-9).

7.4 Laboratory Analysis

7.4.1 Ambient Air Samples:

Air Toxics Ltd. laboratory in Folsom, California analyzed the VOC and SVOC samples. This laboratory holds a New York State Environmental Laboratory Approval Program certification.

VOC analysis: Tenax and Tenax/Anasorb® cartridges were used for the VOC analysis. The laboratory performed the analysis via EPA SW-846 Method 5041A (USEPA 2009a) using gas chromatography/mass spectrometry (GC/MS) in the full scan mode. The tubes were thermally desorbed at 180°C for ten minutes by ultra high purity (UHP) helium carrier gas. The gas stream was then bubbled through 5 mL of organic free water and trapped on the sorbent trap of the purge and trap system. The trap was thermally desorbed to elute the components into the GC/MS system for further separation. See Appendix F4 for the reporting limits for each compound.

The VOC samples collected for the Thomas Jefferson Field and John Mullay Field, twelve VOST Tube pairs for each field, were received by Air Toxics Ltd. on August 23, 2008 and September 3, 2008, respectively, at the recommended temperature (4 $\pm$ 2°C).

SVOC analysis: PUF/XAD Cartridge-Low Volume samples were used for the SVOC analysis and the samples were extracted using Pressurized Fluid Extraction (PFE) by EPA Method 3545A (USEPA 2009a). A modified EPA Method TO-13A (USEPA 2009b) was used to analyze for SVOCs. The sample extract was then concentrated to 1.0 mL and analyzed by GC/MS in the full scan mode. See Appendix F4 for the reporting limits for each compound. Method modifications are detailed in Table 7.2.

The SVOC samples collected at the Thomas Jefferson Field and John Mullaly Field, twelve PUF/XAD Cartridge-Low Volume samples for each field, were received on August 23, 2008 and September 3, 2008, respectively.

7.4.2 Wipe/Microvacuum Samples and Synthetic Grass Analysis:

The particle size distribution and morphology were evaluated by staff in the Microscopy Laboratory in NYSDEC's Bureau of Air Quality Surveillance. Samples were shipped overnight to the laboratory. All samples were received in good condition.

Samples were analyzed microscopically with an Olympus SZX12 Stereomicroscope and a JEOL JSM-6490LV Scanning Electron Microscope (SEM). Fourier Transform Infrared (FTIR) analysis was performed with a Smiths Detection IlluminateIR. Images were collected with either the Olympus Stereomicroscope or the JEOL Scanning Electron Microscope.

7.4.3 Ambient PM_{10} and $PM_{2.5}$ Monitoring:

Since the DR-4000, used to obtain $PM_{2.5}$ and PM_{10} measurements, reports measurements on-site in the field (real-time reporting), laboratory analysis was not necessary.

7.5 Data Review Procedures

7.5.1 Ambient Air Samples:

A review of the laboratory results for the VOC and SVOC data for both fields was conducted by staff in NYSDEC's Chemistry and Laboratory Services Section. The chemist conducting the review noted that results were appropriately qualified when sample results fell outside their respective control limits. A spot check for a particular sample showed that the results were calculated correctly from the values found in the raw data. The chemist noted that all samples were received by the laboratory in "Good" condition and all analytical holding times and temperature storage requirements were met. All blank results were non-detect indicating the absence of any system contamination, which can bias results upwards. All surrogate recoveries fell within the 100 ± 30% control limits indicating that the laboratory was capable of performing the analyses as per method specifications. For more details, the report summarizing this review can be found in Appendix F5.

Descriptive sample location information was matched to sample identifiers in each of data sets received from Air Toxics Ltd.

The VOC, SVOC and TIC results and supporting information (e.g., percent quality match for TICs and field sampling information prepared by RTP) were submitted to NYSDOH for review and analysis. See Section 8. "Assessment of Air Quality Monitoring Survey Data" for additional data review conducted by NYSDOH.

For the Thomas Jefferson field, the ambient temperature during field sampling was 77.2ºF, slightly lower that the goal of 80°F. RTP recorded high surface temperatures throughout the sampling period (118-146 ºF).

For the John Mullaly field, the ambient temperature during field sampling was 84.2ºF and RTP recorded high surface temperatures (121-148ºF) throughout the sampling period.

7.5.2 Wipe/Microvacuum Samples and Synthetic Grass Analysis:

Data reported are qualitative. No further evaluation was conducted.

7.5.3 Ambient PM_{10} and $PM_{2.5}$ Monitoring:

See Section 8. “Assessment of Air Quality Monitoring Survey Data” for data review conducted by NYSDOH.

7.6 Test Results

7.6.1 Ambient Air Samples:

Appendix F6 reports the raw data results for the VOC and SVOC analysis and TICs identified for the samples from the Thomas Jefferson Park. Appendix F7 reports the raw data results for the VOC and SVOC analysis and TICs identified for the samples from the John Mullay Park. See Section 8, “Assessment of Air Quality Monitoring Survey Data” for the data evaluation conducted by NYSDOH.

An evaluation was conducted on the horizontal and vertical concentrations on the fields selecting analytes not commonly found in the urban environmental and those generally found in other studies or reports (NILU 2006, NYCDOHMH 2008b) evaluating releases from crumb rubber infill material. Among those associated with crumb rubber infill, only those analytes found in at least seven locations were retained for this evaluation.

For the Thomas Jefferson Field, the analytes used in the evaluation were 1-ethyl-4-methyl-benzene, decane, nonanal, nonane, and undecane. For the horizontal profile, a linear regression was conducted on the concentrations at the three foot height collection site. The f-statistic for the slope was not significant (α=0.05) for any of the analytes evaluated. An evaluation of the vertical profile was conducted at the downwind location, since this location consistently reported a result for the five analytes evaluated. The f-statistic for the slope was not significant for any of the analytes evaluated**.** Finally, the upwind concentrations for these analytes were compared with the concentrations obtained on-field and downwind. Analysis results, using a Wilcoxon two-sample test indicates no difference ($p>0.05$) in upwind and on-field measurements for these analytes.

For the John Mullaly Field, the analytes used in the evaluation were 2-methyl-butane, ethyl-cyclohexane, nonane, octane, and undecane. The f-statistic for the slope was not significant (α=0.05) for any of the analytes evaluated in the horizontal profile linear regression analysis at locations three feet above the surface. The f-statistic for the

slope was significant (α=0.05) for two analytes (nonane and octane) in the vertical profile analysis. A linear regression was conducted on the vertical profile for these two analytes in samples collected at the center of the field. The f-statistic for the slope at this location for these two analytes was not significant. Finally, the upwind concentrations for these analytes were compared with the concentrations obtained on-field and downwind. Analysis results, using a Wilcoxon two-sample test indicates no difference ($p>0.05$) in upwind and on-field measurements for these analytes.

7.6.2 Wipe/Microvacuum Samples and Synthetic Grass Analysis:

A full copy of the report detailing the results for this analysis can be found in Appendix F8. A summary is presented below.

Blanks: All blanks were characterized as clean and free of particulate.

Duplicate Samples: Duplicate samples consistently matched in collection efficiency.

Particle size and composition: Particle analysis for the wipe and microvacuum samples for both fields revealed a bi-modal distribution of the material collected. Both very large (mm size) and very small particles (micron size) were observed. The large particles were rubber, grass, and cord material. The very small particles were primarily crustal minerals (quartz and calcite) and biologicals (plant material such as pollen or mold). Rubber dust was not found in the smaller particle size range. The large particles were in the several mm range, while the small ones averaged about 5-7 microns. Reported size distributions for the small ones were based on a minimum of 50 particles. In most cases it was difficult for the microscopist to find the minimum of 50 particles. The number of particles available for large particle counting was dependant on the individual filter.

Microvacuum filter particle size analysis of the large (mm size) and small particles (micron size) at the Thomas Jefferson Field revealed that in both cases,

site F1 (the center of the field) had the largest particles, followed by F2 (Northwestern corner of field) and the smallest was F3 (the Southern edge of field).

Microvacuum filter particle size analysis of the large particles (mm size) at the John Mullaly Field revealed that the largest particles were collected at site F2 (Northeastern side of field), followed by F3 (Southern edge of field), and the smallest were observed at F1 (center of the field).

Microvacuum filter particle size analysis of the smaller particles (micron size) at the John Mullaly Field revealed that the largest of the small particles (micron size) were collected at F3 (Southern edge of field), followed by F1 center of the field, and the smallest were observed at F2 (Northeastern side of field).

Synthetic grass: FTIR analysis on the synthetic grass from both fields identifies the fibers as Olefin. Most of the grass fibers were green with a few black fibers contained in the sample. Grass blades varied but were approximately 1 mm in width.

7.6.3 Ambient PM_{10} and $PM_{2.5}$ Monitoring

The results of the particulate matter monitoring conducted at the Thomas Jefferson field can be found in Appendix F9. The results for the particulate matter monitoring conducted at the John Mullaly field can be found in Appendix F10. See Section 8, "Assessment of Air Quality Monitoring Survey Data" for the data evaluation conducted by NYSDOH.

7.7 Conclusions

7.7.1 VOC and SVOC:

An air sampling method was used that allowed for identification of analytes in the nanogram range. Additionally, the laboratory evaluating the samples was asked to

provide results for analytes detected in the crumb rubber off-gassing analysis and to provide results for tentatively identified compounds. With this approach, intended to look for low level concentrations and analytes not previously reported, few analytes were detected and no clear cumulative impact across the horizontal or vertical profile of sampling locations was observed. Many of the analytes detected (e.g., benzene, 1,2,4-trimethylbenzene, ethyl benzene, carbon tetrachloride) are commonly found in the urban environment. A number of analytes detected at low concentrations have also been found in previous studies (Mattina 2007, NYCDOHMH 2008b) evaluating crumb rubber (e.g., 4-methyl-2-pentanone, benzothiazole, alkane chains (C4-C11)).

Although ambient air temperatures during sampling at the Thomas Jefferson field were slightly lower (77.2ºF) than the goal of 80°F, RTP recorded fairly high surface temperatures (118ºF- 146ºF) throughout sampling. Additionally, the types of analytes detected and range of concentrations were similar for this field as compared to the results for the John Mullaly field which was sampled during an ambient temperature of 84.2ºF.

Overall, this study design was sufficient to evaluate chemical releases from these two fields. See Section 8, "Assessment of Air Quality Monitoring Survey Data" for additional conclusions reported by NYSDOH.

7.7.2 Particulate Matter (Surface Wipe, Microvacuum and Ambient PM_{10} and $PM_{2.5}$ Monitoring):

Rubber dust was not found in the respirable range (particles in the micron size diameter range which are able to travel deeply into the respiratory tract, reaching the lungs) through aggressive surface sampling methods (vacuuming of the surface) and by wipe sampling. The respirable particles identified in these samples are primarily crustal or biological in nature. Additionally, the particulate matter sampling ($PM_{2.5}$ and PM_{10}) did not reveal meaningful differences in concentration between the results for the samples collected upwind and those on the field (for the John Mullaly field). This may be explained by the lack of rubber dust found in the smaller size fraction (micron diameter range). See Section 8, "Assessment of Air Quality Monitoring Survey Data" for additional conclusions reported by NYSDOH.

7.8 Limitations

7.8.1 Ambient Air Samples:

The results of this survey are only applicable to fields constructed in the same fashion and with the same type of crumb rubber as those in this study. The results of this survey are not applicable to fields constructed with other types of infill material, nor are they applicable to indoor fields. See Section 8, "Assessment of Air Quality Monitoring Survey Data" for additional limitations reported by NYSDOH.

7.8.2 Ambient PM_{10} and $PM_{2.5}$ Monitoring:

Although fields of different ages were sampled to potentially provide information concerning the relationship between age of the field and PM levels measured above the field, other factors, such as field use and condition, may also influence PM concentrations above synthetic turf fields. An evaluation of these other factors was not conducted. See Section 8, "Assessment of Air Quality Monitoring Survey Data" for additional limitations reported by NYSDOH.

8. Assessment of Air Quality Monitoring Survey Data

The objectives of this assessment were to estimate potential health risks associated with chemical-specific ambient air concentrations measured at the Thomas Jefferson and John Mullaly Fields, and to evaluate the measured particulate matter (PM) concentrations to determine if the fields are a potential source of PM exposure. This section describes the methods used to evaluate the data, the results of the evaluation and limitations of the assessment.

8.1 Volatile and Semi-volatile Organic Chemicals

8.1.1 Data Evaluated

Laboratory analytical results were reported for volatile organic chemicals (VOCs) in 11 air samples and semi-volatile organic chemicals (SVOCs) in 12 air samples, collected at each of the two playing fields. A list of the 140 target chemicals is provided in Appendix F4. The data include results for samples from upwind, on-field and downwind locations, as well as results for laboratory blank samples and field blank samples. The blank sample results help to identify chemicals that may be associated with the laboratory (*e.g.*, common laboratory contaminants) and those that may be associated with the transportation and handling of the samples or with the air sampling equipment. The analytical laboratory also reported estimated concentrations for chemicals that were not on the target chemical list. These chemicals are referred to as "tentatively identified compounds" or TICs. Because the analytical laboratory was not specifically testing for these chemicals, there is some uncertainty as to the precise identity of each TIC. For each TIC, the laboratory reported a "match quality percent" reflecting the extent to which (as estimated by the laboratory computer) the analytical spectrum ("fingerprint") for the chemical in the sample matched a standard reference spectrum. All of the results from the analytical laboratory are provided in Appendix F6 for the Thomas Jefferson field and Appendix F7 for the John Mullaly field. DEC staff performed a quality assurance/quality control review of the data and found it to be acceptable (see Appendix F5).

The analytical laboratory reported data for all chemicals on the target chemical list. Because the reported concentrations for each target chemical are based on comparisons to laboratory standards for that chemical, there is a high level of confidence in the chemical identity and the concentrations reported. The analytical laboratory did not report data for all of the TICs. Only the 20 TICs with the largest chromatographic peaks (*i.e.*, highest estimated concentration) were reported for each sample. The absence of a TIC in a sample does not mean that it was not present, only that it was not among the 20 largest peaks that were reported. However, because neither the identity nor the reported concentrations for TICs are based on comparisons to authentic laboratory standards, there is a lower level of confidence in both the identities and the reported concentrations of TICs than for the target chemicals.

8.1.2 Selecting Chemicals of Potential Concern

This evaluation began by identifying all target chemicals with detectable concentrations for any sample and all TICs for which an estimated concentration value was reported for at least one on-field or downwind sample. Criteria, listed below were applied to focus the health risk evaluation on those chemicals most likely to be associated with the playing fields.

- Chemicals identified in field and laboratory blanks that did not meet the criteria described in the US Environmental Protection Agency's (US EPA) Superfund guidance were eliminated from further evaluation (US EPA, 1989). That guidance indicates that sample results should only be considered positive if concentrations exceed ten-times the concentration of a common laboratory contaminant in a blank, or five-times the concentration of a chemical that is not considered a common laboratory contaminant.

- Chemicals with on-field and downwind concentrations that were not at least 35 percent higher than the concentration in the corresponding upwind sample were

eliminated from further evaluation.[1] If the upwind measurement was reported as not detected, results for on-field and downwind samples were retained.

- TICs that met the previous criterion, but which had a match quality below 85 percent for all samples, were eliminated from further evaluation (US EPA, 1999b).[2]

For TICs that did not meet the 85 percent match quality criterion, the New York City Department of Health and Mental Hygiene report (NYCDOHMH, 2008b) was reviewed to determine if any should be included as a chemical of potential concern because the chemical has been associated with tire rubber or crumb rubber. No additional TICs were included based on this review.

Table 8.1 (Thomas Jefferson Field) and Table 8.2 (John Mullaly Field) summarize the monitoring results for detected target chemicals and TICs. These tables show the reported levels of all target chemicals that were detected in at least one of the samples on each field (27 chemicals for the John Mullaly Field and 21 chemicals for the Thomas Jefferson Field). The tables also show the TICs that were reported for each field, excluding those did not meet the laboratory/field blank criterion described above. Table 8.3 provides a list of the TICs that were present in the blanks (no target chemicals were reported as being detected in the blanks). The majority of target chemicals were not detected in the samples collected at either field.

Tables 8.4 (Thomas Jefferson Field) and 8.5 (John Mullaly Field) present the final list of chemicals that were selected, based on the criteria listed above, for the health risk evaluation.

The chemicals listed in the tables (beginning with Table 8.4) were separated into four categories:

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1 The threshold value of 35 percent (%) was selected based on an analysis of the distribution of percent differences among target compound concentrations reported for paired (co-located) air samples. That review indicated that percent differences among paired samples ranged from 0% to 181%, with a mean of 35%.

- Chemicals detected in the field survey that were also detected in the DEC laboratory off-gassing study.
- Chemicals on the target analyte list detected in the field survey that were not included in the DEC laboratory off-gassing study.
- Chemicals detected in the field survey that were reported as non-detects in the DEC laboratory off-gassing study.
- Chemicals that were detected in the fields survey as TICs.

8.1.3 Approach for Identifying Health-based Inhalation Comparison Values

Chemicals associated with crumb-rubber infilled synthetic turf have the potential to cause non-cancer and (for some chemicals) cancer health effects. Therefore, non-cancer and cancer toxicity values were used to evaluate potential health risks from inhalation exposures. The toxicity value used to evaluate non-cancer effects is the reference concentration, which, as defined by US EPA (2002), is an estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups such as children) that is likely to be without an appreciable risk of deleterious effects during a lifetime of exposure (US EPA, 2002). The toxicity value used to evaluate cancer effects is the chemical concentration in air that is associated with an estimated excess lifetime human cancer risk of one per one-million people (1×10^{-6}). This value is often referred to as the one-in-one-million (or 1×10^{-6}) air concentration. Both kinds of toxicity values are usually used to evaluate continuous, long-term (*e.g.*, lifetime) exposures. Possible chemical exposures that people may have at synthetic turf fields will not be continuous and will be of relatively short duration for any given event. Long-term ("chronic") toxicity values were used to evaluate possible exposures because these values will either be lower than or the same as values that would be used to evaluate shorter-term exposures.

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[2] The US EPA recommends that any chemical with a "match quality percent" less than 85 percent be treated as an "unknown" chemical (US EPA, 1999).

Toxicity values for some of the chemicals identified in the previous section have been derived by state, national or international regulatory or advisory public health organizations. An evaluation of these toxicity values and selected reference concentrations and a 1×10^{-6} air concentrations for use in this analysis was conducted. These chemical-specific toxicity values and the sources of the values are shown in Table 8.6.

For chemicals without an existing reference concentration or a 1×10^{-6} air concentration, each chemical was placed into a chemical class based on its chemical structure, and a surrogate chemical (with a toxicity value) was identified in that class sharing a similar chemical structure. The chemical classes, surrogate chemicals, and toxicity values for these chemicals are shown in Table 8.6.

8.1.4 Approach for Evaluating Potential Non-cancer and Cancer Risks

An evaluation of possible health risks was conducted by comparing the measured air concentrations to the toxicity value(s) for each chemical. To evaluate potential non-cancer effects, a "hazard quotient" was calculated by dividing the measured air concentration by the reference concentration. A hazard quotient that is equal to or less than one is generally not considered to be a significant public health concern. If the measured air concentration of a chemical exceeds the reference concentration, there may be concern for potential non-cancer health effects. Generally, the greater hazard quotient, the greater the level of concern.

To evaluate potential cancer risks, cancer risk estimates were calculated using the measured air concentrations and the 1×10^{-6} air concentration as shown in the following equation:

$$\text{estimated risk level} = \frac{(\text{measured air concentration } (\mu g/m^3)) \times (1 \times 10^{-6})}{1 \times 10^{-6} \text{ air concentration } (\mu g/m^3)}$$

($\mu g/m^3$ = micrograms of chemical per cubic meter of air)

There is general consensus in the scientific and regulatory communities that an increased lifetime cancer risk of one per one-million (10^{-6}) or less is not a significant public health concern and that an increased cancer risk level of greater than one per ten-thousand (10^{-4}) may warrant measures to reduce the risk (*e.g.*, exposure reduction measures). Risk levels that fall between 10^{-4} and 10^{-6} usually warrant further evaluation (*e.g.*, the actual potential for exposure, "background" exposure, and the strength of the toxicological data), with the need for risk reduction measures depending on where in that range the risk estimate falls. There usually is greater concern for risk estimates close to 10^{-4} than for estimates close to 10^{-6}.

8.1.5 Results and Discussion

The results of this evaluation of potential non-cancer risks are shown in Table 8.7 (Thomas Jefferson Field) and Table 8.9 (John Mullaly Field). As shown in these tables, the hazard quotients for all chemicals (target chemicals and TICs) at all sampling locations are below (and in most cases well-below) a value of one. This means that none of the measured concentrations exceed the reference concentrations that were used to evaluate non-cancer health risks. The highest hazard quotients ranged from 0.2 to 0.6 for 1,3-pentadiene, (E)-1,3-pentadiene and 1,4 pentadiene on the Thomas Jefferson Field and from 0.1 to 0.3 for 2-methyl-1,3-butadiene and 1,3-pentadiene on the John Mullaly Field. All of these chemicals are TICs and, as the tables show, there is no consistent pattern in the measurements of these chemicals on the fields. These results do not indicate a public heath concern for non-cancer effects.

The results of the evaluation of potential cancer risks are shown in Table 8.8 (Thomas Jefferson Field) and Table 8.10 (John Mullaly Field). At the Thomas Jefferson Field, the only target chemical with an estimated cancer risk greater than one-in-one-million (10^{-6}) is benzene, and the estimated risks for the on-field samples are essentially no different than the estimated cancer risk for the upwind sample. At the same field, the measured concentrations of the three TICs (1,3-pentadiene, (E)-1,3-pentadiene and 1,4-pentadiene) correspond to estimated cancer risks that range from two-to-four in one hundred thousand (2×10^{-5} to 4×10^{-5}). For 1,3-pentadiene, the cancer risk estimate for

the upwind sample is 2 x 10^{-5}, which is not substantially different than the risk estimates for the on-field samples. (E)-1,3-pentadiene and 1,4-pentadiene were reported in only one of eight of the downwind samples, both of which were collected off of the field. This suggests that the athletic field may not have been the source of these chemicals in air. At the John Mullaly Field, the estimated cancer risks for methylene chloride and chloroform (both of which are target chemicals) are less than 10^{-6}. At the same field, the measured concentrations of the two TICs (2-methyl-1,3-butadiene and 1,3-pentadiene) correspond to estimated cancer risks that range from 8 x 10^{-6} to 2 x 10^{-5}. For 1,3-pentadiene, the estimated cancer risks at the on-field/downwind concentrations are the same as for the upwind concentration at the Thomas Jefferson Field (2 x 10^{-5}). 2-Methyl-1,3-butadiene was only reported in one of the eight downwind samples and the estimated cancer risk for the measured concentration is 8 x 10^{-6}. There is no consistent pattern in the measurements of any of the TICs at either field. These results, combined with the consideration that any exposures at the fields will neither be continuous nor of lifetime duration, do not indicate a public heath concern for cancer effects.

8.2 Particulate Matter (PM)

8.2.1 Data Evaluated

The survey data also included real-time air monitoring results for $PM_{2.5}$ (particulate matter with an aerodynamic diameter of *2.5* microns (μm) or less) and PM_{10} (particulate matter with an aerodynamic diameter of *10* μm or less) at each playing field. Particulate matter was measured at upwind and downwind locations at both fields using DataRAM particle monitors.

At each field, both monitors were initially placed side-by-side for a period of time at the upwind location to obtain a baseline comparison of their responses. After the baseline monitoring period was complete, one of the monitors (referred to as the downwind monitor) was moved to downwind (on-field) monitoring locations.

Both $PM_{2.5}$ and PM_{10} were measured using the same monitors but with different inlet size cutoff devices to measure the two different size fractions. Particulate matter measurements were averaged over one-minute intervals and the monitoring duration at each downwind location was approximately ten minutes. At the Thomas Jefferson Field, $PM_{2.5}$ and PM_{10} were alternately measured at each location. At the John Mullaly Field, all $PM_{2.5}$ measurements were completed prior to measuring PM_{10}. At both fields, sampling staff simulated play with a soccer ball during the monitoring period.

All of the PM monitoring data are available in Appendix F8 for Thomas Jefferson field and Appendix F9 for John Mullaly field.

8.2.2 Approach for Evaluating PM Data

The PM data evaluated consisted of upwind and downwind measurements of $PM_{2.5}$ and PM_{10} at both athletic fields. The real-time instruments used in this study (DataRAMs) differ from the instruments used for air quality monitoring for compliance with the National Ambient Air Quality Standards (NAAQS). Therefore, comparisons between the PM monitoring results in this study and the NAAQS for particulate matter are not appropriate.

To evaluate these data graphs were prepared shown in Figures 8.1-8.3. These figures show the results of the initial baseline (side-by-side) monitoring and the upwind/downwind monitoring. The concurrent side-by-side PM concentrations were evaluated to determine whether the monitors responded similarly to local PM. Additionally, the upwind/downwind concentrations were evaluated to determine if there are meaningful differences in upwind vs. downwind PM measurements.

8.2.3 Results and Discussion

Thomas Jefferson Field

The PM data for Thomas Jefferson Field are shown in Figure 8.1. Examination of this figure shows that the two monitoring instruments differed in their response to PM concentrations during the initial side-by-side upwind monitoring of PM_{10}. Given the short duration of this side-by-side monitoring, an assessment on how the responses of the instruments might or might not vary over time could not be reliably conducted. Therefore, the response variability between the two monitors in evaluating the upwind/downwind results could not be explained. The high initial PM_{10} concentrations for both monitors may have been a result of initial instability in monitor response or because of interaction with the monitors by field staff (*e.g.*, field staff activity in the vicinity of the monitor). For the remaining five minutes in the side-by-side monitoring period, the PM_{10} concentrations measured with the downwind monitor were about two to three micrograms per cubic meter higher than the concentrations measured with the upwind monitor. Initial side-by-side $PM_{2.5}$ monitoring was not conducted at this field.

A notable observation about the sampling results is that $PM_{2.5}$ concentrations sometimes appear to be higher than PM_{10} concentrations, even though the samples were collected minutes apart. Since the PM_{10} size fraction includes $PM_{2.5}$, PM_{10} measurements would generally be expected to be higher than $PM_{2.5}$. Additionally, the PM sampling method at this field involved switching the sample inlet heads for each of the two size fractions monitored. For example, when samples were collected in the center of the field, PM_{10} was measured first (for about 10 minutes) and then the inlet head was changed and $PM_{2.5}$ was measured at the same location. Based on NYSDOH staff experience with this kind of monitor, physical interaction of field staff with the monitors (*e.g.*, changing inlet heads and moving monitors) can result in spikes in the data. In some instances, it appears that the inlet change may have affected the measured PM concentrations, but this was not always the same in both monitors. There may also have been synchronization issues involved in changing the inlets on the two monitors (*i.e.*, the inlet head on one monitor may have been changed at a slightly different time than on the other monitor) that may also account for peaks at the beginning and end of some of the monitoring periods, as observed at times 17:09 and 17:48 in Figure 8.1. Given the similarity in PM concentrations measured by the two monitors and the short duration of monitoring

periods, it is difficult to determine whether the differences in the measurements were due to actual differences PM concentrations or to perturbations in operation of the instruments. The results shown in Figure 8.1 do not show consistent differences between the upwind and downwind results for either $PM_{2.5}$ or PM_{10}, although the data suggest that the downwind levels of $PM_{2.5}$ may have been somewhat higher than upwind levels while activity was occurring on the field. Also, downwind PM_{10} levels appear to be somewhat higher than upwind levels after activity ended. However, for the reasons described above it has been concluded that these data are inadequate for reliably evaluating differences between upwind and downwind measurements.

John Mullaly Field

The PM data for the John Mullaly Field are shown in Figures 8.2 and 8.3. Figure 8.2 shows the results of the initial side-by-side $PM_{2.5}$ monitoring that was conducted for almost 90 minutes. Generally, the two monitors responded similarly, although the $PM_{2.5}$ concentrations measured by the upwind monitor were slightly higher than the concentrations measured by the downwind monitor. The differences (upwind result minus downwind result) ranged from –2 to 5.9 $\mu g/m^3$ with a median value of 1.4 $\mu g/m^3$. No initial side-by-side PM_{10} monitoring was conducted at this field.

Figure 8.3 shows the measured PM levels during on-field deployment. The $PM_{2.5}$ concentrations measured by the upwind monitor were always higher than the concentrations measured by the downwind monitor. The difference in the concentrations ranged from 1 to 6 $\mu g/m^3$. There were only 5 out of 40 data points in the PM_{10} data where the concentrations measured by the downwind monitor exceeded the concentrations measured by the upwind monitor. The difference in the concentrations for these five measurements was always less than 2 $\mu g/m^3$, and on average the measurements at the upwind monitor were higher than at the downwind monitor. While no initial side-by-side PM_{10} monitoring was performed, the differences in the five measurements are within the variability seen during the $PM_{2.5}$ side by side monitoring. Based on these data, there is no indication of meaningful differences between upwind and downwind levels of either PM_{10} or $PM_{2.5}$ at the John Mullaly Field.

8.3 Air Quality Monitoring Survey Conclusions

The measured levels of chemicals in air at the Thomas Jefferson and John Mullaly Fields do not raise a concern for non-cancer or cancer health effects for people who use or visit the fields. Although the particulate matter data for the Thomas Jefferson Field were found to be inadequate for evaluation, data from the John Mullaly Field do not show meaningful differences between upwind and downwind levels of either PM_{10} or $PM_{2.5}$.

8.4 Air Quality Monitoring Survey Limitations

The results of this survey do not identify a public health concern for the levels of chemicals or particulate matter measured at the two turf fields. While the survey was designed to collect data under conditions representative of "worst case" conditions (*e.g.*, summer-time temperatures that should maximize off-gassing of chemicals), samples collected under different conditions, using different methods or at different fields could yield different results. For example, concentration measurements may be different for fields of other ages or designs (*e.g.*, different volumes of crumb rubber infill, non-crumb rubber infill) or for indoor fields.

9. Temperature Survey

9.1 Objectives and Design

The temperature survey was performed to gain a better understanding of the surface temperature of synthetic turf fields and the potential for field users to suffer from heat-related illness ("heat stress"). The indicators of heat stress used in this survey are the wet bulb globe temperature and heat index. These indicators and surface temperature were measured above the surface of the synthetic turf and as comparison these measurements were made above a nearby grass and sand surface. The initial objective of the survey was to capture a range of surface temperatures and above surface heat stress indicator measurements throughout changing ambient summer temperatures and humidity levels.

Synthetic turf fields absorb solar radiation; therefore, the field measurements were conducted in areas that are subject to direct solar radiation. Discrete temperature measurements over these surfaces were conducted at short-time intervals as opposed to a continuous evaluation over time. Measurements were generally made from, noon to 2:00 PM, which other studies identified as the time of day with the highest surface temperatures (DeVitt et al. 2007, Williams 1991).

Surface temperatures were measured using an infrared thermometer. The potential for heat stress was assessed by measuring the wet bulb globe temperature (WBGT) since the American Academy of Pediatrics (AAP) has issued a policy statement addressing heat stress and exercising children and adolescents based on this index (AAP 2000). The AAP uses the WBGT since it can be measured in the field and incorporates factors (i.e., radiant heat, humidity, wind and temperature) that influence heat illness for an individual. The WBGT was compared to the AAP guidance on heat stress for exercising children and adolescents to assess the potential for heat stress. The National Federation of State High School Associations also recommends the use of the WBGT to assess potential heat stress during sports participation (NFSHSA 2001).

9.2 Measurements and Collection Methods

9.2.1 Measurement Locations and Protocol

Because the surface temperature of synthetic turf is dependent on the amount of sunlight received, the edge of the field should have cooler temperatures due to shade cover from nearby trees, while the center should have warmer temperatures because it was subject to full sun. Therefore, for each field in this study, the center and a shaded edge area were selected for measurements and both areas were comprised of green-colored synthetic grass. For the Thomas Jefferson field, an additional center location was selected consisting of white synthetic grass.

Measurements on each synthetic turf field were immediately followed by measurements on a nearby grass area and sand surface of a baseball field – both areas in full sun. All parameters recorded on the synthetic turf fields were recorded for the nearby comparison areas.

To account for instrument variability and rapid changes in cloud cover, three sequential measurements per area were obtained.

The Field Measurement Protocol – Temperature and Heat Stress (attached as Appendix H1) provides details for the collection of field measurements. As stated in the Protocol, if weather conditions changed between the synthetic turf and comparison area measurements, the synthetic turf would be re-measured to obtain field measurements under similar conditions for all areas. During actual field measurements, the cloud cover changed fairly rapidly, albeit subtly, making it difficult for field staff to obtain measurements under identical conditions for the different areas (synthetic turf versus comparison areas).

9.2.2 Instrumentation for Collection of Surface Temperature and Heat Stress Measurements

Surface temperature was recorded using an infrared thermometer (DeltaTrak Thermo Trace, Model #15006). Wet bulb globe temperature was recorded using a thermal environmental and heat stress monitor (Quest Technologies QUESTemp°36). The temperatures used to calculate WBGT (wet bulb (WB), dry bulb (T), and globe (G)) and the relative humidity were also recorded. The instrument reports the wet bulb globe temperature based on the following formula: WBGT = 0.7 WB + 0.2 G + 0.1 T. WB is a

measure of evaporative cooling and integrates the effects of wind, humidity and radiant heat. In the presence of solar radiation, G integrates the effects of radiant heat, wind and air temperature. T is the ambient air temperature.

The heat index (HI), another indicator of potential heat stress, was calculated from the dry bulb temperature and relative humidity[3] (NOAA 2009). The WBGT instrument also has the capability of recording wind speed but during field deployment the instrument malfunctioned and this value was not recorded. General meteorological observations such as cloud cover and qualitative information about field conditions such as whether or not the grass was recently watered or cut also were recorded.

9.2.3 Measurement Dates

Field measurements were conducted in August (11 days) and September (6 days). Meteorological data from the New York City Central Park monitor for the years 2000 – 2007 were used to derive a historical profile of average, and 50th and 90th percentile temperature and relative humidity values for each of the two months. Information on daily maximum temperature, and daily minimum relative humidity and rain events for the dates of sampling from this data source also was obtained. A goal of the study was to conduct field measurements representative of high ambient conditions, therefore field temperatures were measured when the ambient temperature was above the 90th percentile and relative humidity was expected to be above the 50th percentile based on historical data. A second target scenario to capture field measurements was during average temperature conditions for the month.

9.3 Data Review Procedures

The three sequential measurements per area were averaged together. The heat index was calculated from dry bulb temperature and relative humidity. The WBGT index was calculated from the individual measures to verify instrument reporting of this value.

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[3] The formula for heat index is: $-42.379 + 2.04901523T + 10.14333127R - 0.22475541TR - 6.83783x10^{-3}T^2 - 5.481717x10^{-2} R^2 + 1.22874x10^{-3}T^2R + 8.5282x10^{-4} TR^2 - 1.99x10^{-6} T^2 R^2$, where T = ambient dry bulb temperature degrees Fahrenheit and R = relative humidity

Meteorological data from a monitor in Central Park were used to determine whether the measurement dates were representative of high ambient conditions and average scenario goals stated previously[4]. Daily maximum temperature and minimum relative humidity data, summarized for the years 2000-2007, were used to evaluate the conditions on the dates of the field measurements.

9.4 Analysis Methods

A graphical display was used to facilitate comparisons of the surface temperature measurements between the synthetic turf and comparison locations. Tests for normality and autocorrelation were conducted and the appropriate statistical comparison was performed. Coefficient of variation was calculated to facilitate comparison between surface and ambient temperature. In the absence of a formal established peer-reviewed guideline value, the surface temperature measurements were compared to a guideline value issued by Brigham Young University (BYU). BYU has set a surface temperature guideline of 120°F (Williams, 2002) as the limit for conducting activities on synthetic turf fields. The BYU Safety Office based this value on studies relating temperature to skin damage and not on data related to synthetic turf fields and potential injury (Ed Jackson BYU Safety Office, personal communication, 12/16/08).

The WBGT indicator of heat stress was compared with the AAP guidelines (AAP, 2000) which are shown in Table 9.1. Additionally, the HI was compared with guidelines issued by the National Weather Service (NWS 2005). The NWS has developed a set of guidelines to warn people about conditions that may lead to heat stress at various HI levels and employs alert procedures when the HI is expected to exceed 105°F. Tests for normality and autocorrelation were conducted and statistical tests were performed to compare surface temperatures and the indicators of heat stress for the different surfaces.

[4] Comparison data for 2008 from the Central Park monitor were only available in summary format of daily average, minimum and maximum values for temperature and relative humidity and total daily rainfall. Since field measurements were taken a warm part of the day (40% of the measurements were taken at 1:00 PM), it was recommended (John Kent, Air Pollution Meteorologist, NYSDEC, personal communication 11/21/08) to use the daily maximum for temperature and minimum relative humidity to best represent the actual field measurement conditions.

The rain event data was reviewed and was found not to be useful for examining the effects of field watering on surface temperature, and humidity and indicators of heat stress measurements.

9.5 Results and Discussion

General meteorological and environmental observations were recorded by field staff during each site visit. On many occasions, field staff noted a rapid decline in surface temperature when incident solar radiation was interrupted by cloud cover and the opposite, a rise in temperature when cloud cover passed. All field measurements were collected within a short period of time. For the Thomas Jefferson field, all measurements were collected within 41 minutes, on average. For the John Mullaly field, all measurements were collected within 26 minutes, on average. A summary of all parameters measured for the Thomas Jefferson field can be found in Appendix H2 and for the John Mullaly field in Appendix H3.

9.5.1 Meteorological Data

Table 9.2 shows the average, range 50th and 90th percentiles of daily maximum temperature and daily minimum relative humidity for 2000-2007 and the dates of field measurements. The average daily maximum ambient temperatures during the dates of field measurements are nearly identical to the average daily maximum 2000-2007 temperatures. The minimum daily relative humidity profile appears to be lower for the dates of measurements as compared to previous years. Measurements greater than or equal to the 90th percentile (for the summarized years of 2000-2007) of daily maximum temperature for the month of August were not obtained, although this goal was achieved for the month of September. Overall, the goal of capturing measurements during typical August and September days was met based on daily maximum temperature but the daily minimum relative humidity measurements are lower than previous years.

9.5.2 Surface Temperatures

Thomas Jefferson Field

Figure 9.1 illustrates the surface temperatures for measurement dates at all five locations (three on synthetic turf and two comparison areas) for the Thomas Jefferson field. The graph shows that the surface temperatures of the synthetic turf were typically higher and were more variable than the surface temperatures of the comparison areas. In general, the surface temperatures in September are lower than the surface temperatures in August (on average, eight degrees lower for green sections). The figure also shows the BYU guideline temperature. At least one location on the turf field was above 120°F guideline for 12 out of 17 dates of measurements (70%), while the comparison areas never exceeded 110°F.

The dry-bulb temperatures (recorded with the QUESTemp°36 monitor at a 3ft height) at all locations on the synthetic turf field, grass and sand was compared with the temperatures obtained from the nearest meteorological station, located in Central Park. On average, all values were within 1 % (Central Park data not shown, dry-bulb measures from the field can be found in Appendix H2) of each other as demonstrated by comparison ratios, with maximum differences of approximately 8.0%. This evaluation reveals little difference between the ambient temperatures above these surfaces and the nearest meteorological station. This comparison also indicates little difference in dry-bulb temperature above the synthetic turf field versus the comparison areas. The ambient temperature obtained from the measurements over the center green section of the synthetic turf is displayed in Figure 9.1.

The coefficient of variation (CV) was calculated across dates for surface temperatures at the center section and the corresponding ambient temperature measured above that location. The average CV for surface temperature was 0.19, whereas the CV for ambient temperature was 0.074. Because the variability was significantly lower for the dry-bulb temperature above these surfaces, a direct relationship between ambient air temperature and synthetic surface temperature (which is highly variable) cannot be readily inferred from these data.

A summary of the temperature differences between the synthetic turf and grass and synthetic turf and sand is illustrated in Table 9.3. Surface temperatures for the synthetic turf field, grass and sand approximated log-normal distributions, with median temperatures of 132, 87, and 86°F, respectively and geometric mean temperatures of 126,

87, and 88°F. The average synthetic turf surface was 42°F higher than the grass surface temperature and 40°F higher than the sand surface temperature. The Durban-Watson test statistic indicates the surface temperature data are not autocorrelated. The mean log-transformed surface temperature for the synthetic turf field was significantly higher ($p<0.0001$) than that of the natural grass and sand using paired Student's t-test. Statistical comparisons between the grass and sand showed little differences ($p>0.10$).

John Mullaly Field

Figure 9.2 illustrates the surface temperatures at all four measurement locations (two synthetic turf, one grass, one sand) along with the BYU guideline value of 120°F. Nine out of 17 dates of measurements (53%) had at least one location on the synthetic turf field above 120°F. Also displayed is the ambient temperature recorded by the dry-bulb thermometer above the synthetic turf field.

The coefficient of variation (CV) was calculated across dates for surface temperatures at the center section and the corresponding ambient temperature measured above that location. The average CV for surface temperature was 0.16, whereas the CV for ambient temperature was 0.085. Because the variability was significantly lower for the dry-bulb temperature above these surfaces, a direct relationship between ambient air temperature and synthetic surface temperature (which is highly variable) cannot be readily inferred from these data.

Comparisons between the synthetic turf, grass and sand surface temperatures for the same day are illustrated in Table 9.4. Surface temperatures for the synthetic turf field, grass and sand approximated log-normal distributions, with median temperatures of 119, 80 and 90°F, respectively and geometric mean temperatures of 114, 80, and 89°F. The average synthetic turf surface was 26°F higher than the grass surface temperature and 35°F higher than the sand surface temperature. The Durban-Watson test statistic indicates the surface temperature data are not autocorrelated. The mean log-transformed surface temperature for the synthetic turf field was significantly higher ($p<0.0001$) than that of the natural grass and sand using paired Student's t-test. Statistical comparisons between the grass and sand surface also were statistically different ($p<0.001$).

9.5.3 Heat Stress Indicators

Thomas Jefferson Field

Figure 9.3 shows the results of the WBGT measurements for all locations. Little variability in WBGT values (compared to surface temperature) is noted across the three surface types for each measurement date. Across dates of measurements (inclusive of all surface types), the average CV for WBGT was 0.020, whereas the average CV for surface temperature was 0.21. WBGT measurements for the synthetic turf field, grass and sand approximated log-normal distributions, with median temperatures of 76, 78, and 78°F, respectively and geometric mean temperatures of 76, 76, and 76°F. The comparisons of the mean log-transformed WBGT measurement between all surface types (synthetic turf, grass and sand) were not statistically different ($p>0.05$) using paired Student's t-test.

Threshold values that correspond to the AAP guidelines for exercising children are also shown in Figure 9.3. The highest WBGT recorded was 85°F on the synthetic turf. Following the AAP guidelines, a recommendation could have been made to cancel all activities when this heat stress level was reached. For the same date, the WBGT values for the other locations were within in the range of 79 - 84°F. At these levels, the AAP guidelines recommend stopping activities for unacclimatized persons and limiting activities for all other individuals (e.g., disallow long-distance races, reduce amount of time spent exercising). On eight days, the maximum WBGT values for one or more surfaces were also within the range of 79 - 84°F. On three days the maximum WBGT values for one or more surfaces were within the range of 75 - 79°F. At these levels, the AAP guidelines recommend longer rest periods in the shade and an increase in fluid intake. Use of the AAP guidelines could have led to the recommendation of some activity limitation on one or more of the surfaces for 12 of the 17 days of measurements. All the surfaces appear to be similarly impacted and similar recommendations could apply to all surfaces.

The heat index values are reported in Appendix H2. Following guidelines issued by the NWS, approximately 56% of the heat index values (across all measurement locations) are above 80°F and the NWS warns that fatigue is possible with prolonged

exposure and/or physical activities. There was little difference in the HI measurements between the synthetic turf and comparison areas.

John Mullaly Field

Figure 9.4 illustrates the WBGT recorded for John Mullaly Park. The figure shows little variability in WBGT values for each measured date across the three surface types. Across dates of measurements, the average CV for WBGT was 0.020, whereas the average CV for surface temperature was 0.19. WBGT measurements for the synthetic turf field, grass and sand approximated log-normal distributions, with median temperatures of 77, 76, and 76°F, respectively and geometric mean temperatures of 75, 75, and 75°F. The comparisons of the mean log-transformed WBGT measurement between all surface types (synthetic turf, grass and sand) were not statistically different ($p>0.05$) using paired Student's t-test.

Threshold values that correspond to the AAP guidelines for exercising children are also shown in Figure 9.4. The highest WBGT recorded on the synthetic turf was 82°F. For the same date, the WBGT values for the other locations were also within in the range of 79 - 84°F. At these levels, the AAP guidelines recommend stopping activities for unacclimatized persons and limiting activities for all other individuals.

On ten of the 17 days of measurements, the maximum WBGT value for at least one of the surfaces fell within the range of 79 - 84°F. On two days, the maximum WBGT value for all of the surfaces fell within the range of 75 - 79°F. At these levels, the AAP guidelines recommend longer rest periods in the shade and an increase in fluid intake. All of the surfaces had a WBGT that exceeded 75ºF on multiple occasions during the 17 days of measurements.

The heat index values are reported in Appendix H3. Following guidelines issued by the NWS, approximately 65% of the heat index values (across all measurement locations) are above 80°F and the NWS warns that fatigue is possible with prolonged exposure and/or physical activities. There was little difference in the HI measurements between the synthetic turf and comparison areas.

9.6 Conclusions

9.6.1 Surface Temperatures

These results show significantly ($p<0.0001$) higher surface temperatures for both synthetic turf fields compared to the grass and sand surfaces. The average differences between synthetic turf and grass were 42°F and 35°F for the Thomas Jefferson field and John Mullaly field, respectively. The average differences between synthetic turf and sand (measured at a baseball field) were 40°F and 26°F for the Jefferson and Mullaly fields, respectively.

Buskirk et al. (1971) reported that the interior of a shoe can reach high temperatures when in contact with synthetic turf of elevated temperature. However, peer-reviewed studies reporting thermal burns attributable to contact with these types of synthetic turf surfaces were not identified and NYSDEC and NYSDOH staff are not aware of widespread reports of people receiving thermal burns from these surfaces. Staff acknowledge that direct contact with surfaces of elevated temperature has the potential to create discomfort and may cause thermal injury.

9.6.2 Heat Stress

Relatively little difference was found for WBGT levels across the different surface types, however, on any given day; a small difference in WBGT could result in different guidance for the different surface types under the AAP guidelines. Following the AAP guidelines for limitations on activities at different WBGT levels, approximately 70% of the measurement dates at the Thomas Jefferson field and 70% of the measurement dates at the John Mullaly Field could have warranted some type of guidance for exercising children and adolescents for one or more of the surface types evaluated in this survey. The AAP guidelines are shown in Table 9.1.

This survey also found that the calculated heat indices exceeded the level at which the NWS issues advice regarding the potential for heat stress.

The WBGT is one indicator of heat stress and is based on three factors; humidity, solar radiation and ambient temperature. The heat index is based on two factors; relative humidity and ambient temperature. Many other factors (e.g., an individual's activity level and skin resistance to heat transfer) contribute to elevating body temperatures

(Steadman 1979a, Steadman 1979b). Although little difference between heat stress indicator measurements for the synthetic turf, grass, and sand were found, the surface temperatures recorded were much higher for the synthetic turf suggesting a greater potential for heat stress might exist since the body could be in prolonged contact with a surface of elevated temperature. Additionally, high metabolic activity generated during active play, in addition to the heat input from the surfaces, could produce a situation leading to greater potential for heat stress on these surfaces.

9.7 Limitations

Surface temperature measurements were not recorded during the warmest summer month, July (Fisk, 2009) and an evaluation of the environmental conditions (such as presence of shade trees, different field configurations) which may lead to lower surface temperatures was not conducted.

The two common indicators of potential heat stress measured are based on a limited number of factors (e.g., humidity, solar radiation and ambient temperature). But a number of other factors, not assessed in this survey could contribute to heat related-illness. External factors such as contact with a heat source and the amount and type of clothing worn by an individual as well as internal factors including decreased ability to sweat, hydration, lack of acclimatization and less efficient heat dissipation affect the body's ability to maintain a normal range in core temperature. The indicators of heat stress reported in this survey do not include these other factors.

Finally, this survey was not intended to determine the factors contributing to the elevation in surface temperatures for synthetic turf fields. Measurements taken on other synthetic turf surfaces constructed differently or in different locations might yield different findings.

10. Conclusions

10.1 Laboratory Analysis of Crumb Rubber Samples

10.1.1 Laboratory SPLP

The results of this evaluation, using aggressive leaching methods, indicate a potential for release of zinc, aniline, phenol, and benzothiazole. Zinc (solely from truck tires), aniline, and phenol have the potential to be released above groundwater standards or guidance values. No standard or guidance value exists for benzothiazole. It is important to note that this test method may not be representative of actual field conditions, and therefore may result in an overestimate of the release of pollutants under these conditions. Additionally, the results indicate that the leaching potential is dependent on the type of crumb rubber, with truck tires reporting the highest leaching potential.

10.1.2 Laboratory Total Lead Analysis (Acid Digestion Method)

The lead concentration in the crumb rubber samples are below the USEPA's hazard standard for lead in bare soil and below applicable standards used by others evaluating lead concentrations on synthetic turf fields (NYCDOHMH, 2008a). These data indicate that the crumb rubber from which the samples were obtained would not be a significant source of lead exposure if used as infill material in synthetic turf fields.

10.1.3 Laboratory Off-gassing Test

Although the laboratory off-gassing portion of the study proved difficult to conduct quantitatively due to the strong absorptive nature of the crumb rubber samples for VOCs, the results did provide useful information for additional analytes to be included in the laboratory analysis of the ambient air field samples. The five additional analytes were selected for inclusion in the ambient air survey based on the results of the crumb rubber off-gassing study. Three analytes were selected for inclusion in the air survey because of high toxicity (i.e., low reference concentration): aniline (CAS# 62-53-3), 1,2,3-trimethylbenzene (526-73-8), and 1-methylnapthalene (90-12-0). Two analytes

were selected because of high frequency of detects and high relative concentrations found in the off-gassing study: benzothiazole (95-16-9), and tert-butylamine (75-64-9). Finally, it is uncertain what effect the absorptive nature of the crumb rubber, as noted in the laboratory setting, may have in the field setting.

10.2 Laboratory Column Test

The column test procedure was considered to be more representative of field conditions and, as expected, the concentration of all elements of concern were lower than of the concentrations measured in the more aggressive SPLP for the two types of crumb rubber evaluated. Phenol and aniline leachate results were above the groundwater standards and these analytes were included in the surface water and groundwater evaluation.

10.3 Water Quality Survey at Existing Fields

10.3.1 Surface Water Sampling

Only one surface water runoff sample was collected during the study period presented in this report. Based on test results of this sample, no organics were detected and several metals were detected at low levels. One sample is not sufficient to draw a conclusion, so additional analyses will be performed in 2009 and presented in a separate report.

10.3.2 Groundwater Sampling

Thirty-two samples of groundwater were collected during the study period presented in this report. Based on test results of these samples, no organics or zinc were detected. The NYSDEC will perform additional sampling of groundwater at sites with shallower groundwater levels in 2009 to better represent potential impacts and will present test results in a separate report.

10.4 Potential Groundwater Impacts

The dilution-attenuation factor (DAF) from the NYSDEC's soil cleanup guidance for hazardous remediation sites was applied and demonstrates that crumb rubber may be used as an infill without significant impact on groundwater quality.

10.5 Potential Surface Water Impacts

A risk assessment for aquatic life protection was performed and found that crumb rubber derived entirely from truck tires may have an impact on aquatic life based on the impacts that zinc may have on aquatic life pathway. For the crumb rubber made from mixed tires, the potential impacts are insignificant.

10.6 Air Quality Monitoring Survey at Existing Fields

10.6.1 VOC and SVOC Conclusions

An air sampling approach, intended to look for low level concentrations was used and few detected analytes were found with no clear cumulative impact across the horizontal or vertical profile of sampling locations. Many of the analytes detected (e.g., benzene, 1,2,4-trimethylbenzene, ethyl benzene, carbon tetrachloride) are commonly found in the urban environment. At low concentrations a number of analytes were detected that have been found in previous studies evaluating crumb rubber (e.g., 4-methyl-2-pentanone, benzothiazole, alkane chains (C4-C11)).

The types of analytes detected and range of concentrations were similar at both fields, even though surface and ambient temperatures differed at the time of sampling.

See Section 8, "Assessment of Air Quality Monitoring Survey Data" for additional conclusions reported by NYSDOH.

10.6.2 Particulate Matter

Rubber dust was not identified in the respirable range (particles in the micron size diameter range which are able to travel deeply into the respiratory tract, reaching the lungs) through aggressive sampling methods (vacuuming of the surface) and by wipe sampling. The small size particles identified were primarily crustal or biological in

nature. See Section 8, "Assessment of Air Quality Monitoring Survey Data" for additional conclusions reported by NYSDOH.

10.7 Assessment of Air Quality Monitoring Survey Data

The measured levels of chemicals in air at the Thomas Jefferson and John Mullaly fields do not raise a concern for non-cancer or cancer health effects for people who use or visit the fields. Although the particulate matter data for the Thomas Jefferson Field were found to be inadequate for evaluation, data from the John Mullaly Field do not show meaningful differences between upwind and downwind levels of either PM_{10} or $PM_{2.5}$. Therefore, these synthetic turf fields are not important contributors of exposure to particulate matter.

10.8 Temperature Survey

10.8.1 Surface Temperatures

The results show significantly ($p<0.0001$) higher surface temperatures for both synthetic turf fields compared to the grass and sand surfaces. The average differences between synthetic turf and grass were 42°F and 35°F for the Thomas Jefferson field and John Mullaly field, respectively. The average differences between synthetic turf and sand (measured at a baseball field) were 40°F and 26°F for the Jefferson and Mullaly fields, respectively.

Although this survey reported significantly high surface temperatures and previous research indicates that the interior of the shoe can reach high temperatures when in contact with synthetic turf of elevated temperature (Buskirk et al. 1971), peer-reviewed studies reporting thermal burns attributable to contact with these types of synthetic turf surfaces were not identified. NYSDEC and NYSDOH staff acknowledge that direct contact with the surfaces of elevated temperature has the potential to create discomfort and may cause thermal injury.

10.8.2 Heat Stress

Relatively little difference for WBGT levels was found across the different surface types, however, on any given day, a small difference in WBGT could result in different guidance for the different surface types under the AAP guidelines. Following the American Academy on Pediatrics (AAP) guidelines for limitations on activities at different WGBTs, approximately 70% of the measurement dates could require some type of advice for exercising children and adolescents for both the synthetic turf and natural grass surfaces.

Although little difference between heat stress indicator measurements for the synthetic turf, grass, and sand were found, the surface temperatures recorded were much higher for the synthetic turf suggesting a greater potential for heat stress might exist since the body could be in prolonged contact with a surface of elevated temperature.

11. Follow-up Actions

11.1 Water Releases from Synthetic Turf Fields

- NYSDEC will perform additional sampling of surface water and groundwater near synthetic turf fields with crumb-rubber infill and present its findings in a separate report.

11.2 Surface Temperature and Heat Stress

- NYSDOH will continue to identify and implement measures to make the public, including users and managers of synthetic turf fields, aware of the following:
  (1) the dangers of heat-related illness,
  (2) symptoms of heat-related illness,
  (3) settings or conditions that increase the risk of heat-related illness, and
  (4) measures that can be taken to reduce the potential for heat-related illness.

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Tables

Table 2.1 Description of Crumb Rubber Samples

Facility Number	Production Rate (Million lbs per month)	Sample Type	Number of Samples
#1	10	Ambient/Truck	7
		Ambient/Car	7
#2	0.5	Ambient/Mixed	5
#3	0.6	Ambient/Mixed	5
#4	3	Cryogenic/Mixed	7

Table 2.2 Summary of SPLP Leaching Test Results for Metals (All 31 Crumb Rubber Samples)

	1st SPLP		2nd SPLP		Groundwater Standard/ Guidance Value, µg/L
	% Detected	Average [a], µg/L	% Detected	Average [a], µg/L	
Detected metals					
Zinc	100	1947.4 ± 419.3	100	1150.1 ± 95.4	2000
Calcium	96.8	2443.5 ± 251.8	29	1736.1 ± 286.3	No Standard
Manganese	77.4	20.7 ± 1.8	22.6	13.9 ± 1.4	300
Barium	19.4	30.4 ± 3.6	3.2	22	1000
Iron	12.9	1704.8 ± 717.8	3.2	105	300
Copper	9.8	296.3 ± 120.7	0	0	200
Lead	9.7	12.8 ± 1.2	0	0	25
Non-detected metals [b]					
Aluminum	0	< 100			
Antimony	0	< 60			
Arsenic	0	< 10			
Beryllium	0	< 5			
Cadmium	0	< 5			
Chromium	0	< 10			
Cobalt	0	< 50			
Magnesium	0	< 1000			
Mercury	0	< 0.2			
Molybdenum	0	< 25			
Nickel	0	< 40			
Potassium	0	< 2000			
Selenium	0	< 10			
Silver	0	< 10			
Sodium	0	< 1000			
Thallium	0	< 10			
Vanadium	0	< 50			

[a] Average ± standard error for detected results only
[b] Not detected at detection limit

Table 2.3 Summary of SPLP Leaching Test Results for SVOCs (All 31 Crumb Rubber Samples)

Analytes	CASRN	1st SPLP		2nd SPLP		Ground-water Standard/ Guidance Value (µg/L)
		% Detect	Average[a] (µg/L)	% Detect	Average[a] (µg/L)	
Detected Compounds						
Aniline	62-53-3	100	103.4 ± 15.5	100	62.7 ± 6.4	5
Phenol	108-95-2	100	12.8 ± 1.1	100	4.1 ± 0.6	1
N-Nitrosodiphenylamine	86-30-6	100	3.6 ± 0.3	100	3.3 ± 0.3	50
Isophorone	78-59-1	97	3.6 ± 0.3	45	1.4 ± 0.1	50
4-Methylphenol	106-44-5	94	3.2 ± 0.3	48	1.4 ± 0.2	1
Acetophenone	98-86-2	74	2.3 ± 0.2	19	1.6 ± 0.1	No Standard
Diethyl Phthalate	84-66-2	71	1.7 ± 0.2	39	1.6 ± 0.1	50
Benzoic Acid	65-85-0	29	19.8 ± 5.7	0	0	No Standard
Bis(2-ethylhexyl) Phthalate	117-81-7	28	1.6 ± 0.2	19	1.1 ± 0.1	5
2-Methylphenol	95-48-7	19	1.4 ± 0.2	0	0	1
Naphthalene	91-20-3	16	1.4 ± 0.2	16	1.3 ± 0.1	10
Di-n-butyl Phthalate	84-74-2	6	1.2 ± 0.3	1	1.8	50
Carbazole	86-74-8	6	1.4 ± 0.1	6	1.2 ± 0.1	No Standard
2,4-Dimethylphenol	105-67-9	6	2.6 ± 0.4	0	0	1
Benzyl Alcohol	100-51-6	3	2.8	0	0	No Standard
Non-detected Compounds						
Acenaphthene	83-32-9	0	< 10[b]			
Acenaphthylene	208-96-8	0	< 10			
Anthracene	120-12-7	0	< 10			
Benz(a)anthracene	56-55-3	0	< 10			
Benzo(a)pyrene	50-32-8	0	< 10			
Benzo(b)fluoranthene	205-99-2	0	< 10			
Benzo(g,h,i)perylene	191-24-2	0	< 10			
Benzo(k)fluoranthene	207-08-9	0	< 10			
Butyl Benzyl Phthalate	85-68-7	0	< 10			
Indeno(1,2,3-	193-39-5	0	< 10			

Analytes	CASRN	1st SPLP		2nd SPLP		Ground-water Standard/ Guidance Value (μg/L)
		% Detect	Average[a] (μg/L)	% Detect	Average[a] (μg/L)	
cd)pyrene						
4-Chloroaniline	106-47-8	0	< 10			
Bis(2-chloroethoxy)methane	111-91-1	0	< 10			
Bis(2-chloroethyl) Ether	111-44-4	0	< 10			
2-Chloronaphthalene	91-58-7	0	< 10			
2-Chlorophenol	95-57-8	0	< 10			
Bis(1-chloroisopropyl) ether	108-60-1	0	< 10			
Chrysene	218-01-9	0	< 10			
Dibenz(a,h)anthracene	53-70-3	0	< 10			
Dibenzofuran	132-64-9	0	< 10			
1,3-Dichlorobenzene	541-73-1	0	< 10			
1,2-Dichlorobenzene	95-50-1	0	< 10			
1,4-Dichlorobenzene	106-46-7	0	< 10			
3,3'-Dichlorobenzidine	91-94-1	0	< 10			
2,4-Dichlorophenol	120-83-2	0	< 50			
Dimethyl Phthalate	131-11-3	0	< 10			
2,4-Dinitrophenol	51-28-5	0	< 10			
2,4-Dinitrotoluene	121-14-2	0	< 10			
2,6-Dinitrotoluene	606-20-2	0	< 10			
Fluoranthene	206-44-0	0	< 10			
Fluorene	86-73-7	0	< 10			
Hexachlorobenzene	118-74-1	0	< 10			
Hexachlorobutadiene	87-68-3	0	< 10			
Hexachlorocyclo-pentadiene	77-47-4	0	< 10			
Hexachloroethane	67-72-1	0	< 10			
2-Methylnaphthalene	91-57-6	0	< 10			
4,6-Dinitro-2-methylphenol	534-52-1	0	< 50			
4-Chloro-3-methylphenol	59-50-7	0	< 10			
2-Nitroaniline	88-74-4	0	< 50			
3-Nitroaniline	99-09-2	0	< 50			
4-Nitroaniline	100-01-6	0	< 50			
Nitrobenzene	98-95-3	0	< 10			

Analytes	CASRN	1st SPLP		2nd SPLP		Ground-water Standard/ Guidance Value (μg/L)
		% Detect	Average[a] (μg/L)	% Detect	Average[a] (μg/L)	
2-Nitrophenol	88-75-5	0	< 10			
4-Nitrophenol	100-02-7	0	< 10			
N-Nitrosodimethylamine	62-75-9	0	< 10			
Di-n-octyl Phthalate	117-84-0	0	< 10			
Pentachlorophenol (PCP)	87-86-5	0	< 50			
Phenanthrene	85-01-8	0	< 10			
4-Bromophenyl phenyl Ether	101-55-3	0	< 10			
4-Chlorophenyl phenyl Ether	7005-72-3	0	< 10			
N-Nitro0sodi-n-propylamine	621-64-7	0	< 10			
Pyrene	129-00-0	0	< 10			
1,2,4-Tri0chlorobenzene	120-82-1	0	< 10			
2,4,6-Tric0hlorophenol	88-06-2	0	< 10			
2,4,5-Trich0lorophenol	95-95-4	0	< 10			

[a] Average ± SE (standard error) for detected results only
[b] < 10 = Not detected at 10 μg/L detection limit

Table 2.4 TICs Found in SPLP Leaching Test Results (All 31 Crumb Rubber Samples)

Detected Compounds	CAS #	1st SPLP		Groundwater Standard/Guidance Value, μg/L
		% Detected	Average,[a] μg/L	
Benzothiazole	95-16-9	100	526.3 ± 47.6	No Standard
Cyclohexanamine, N-cyclohexyl	101-83-7	100	208.1 ± 37.4	No Standard
Methyl Isobutyl Ketone	108-10-1	100	173.5 ± 24.3	No Standard
2(3H)-Benzothiazolone	934-34-9	100	261.9 ± 11.1	No Standard
Phthalimide	85-41-6	100	108.6 ± 11.3	No Standard
2-Mercaptobenzothiazole	149-30-4	87	52.4 ± 6.9	50
Cyclohexane, isothiocyanato-	1122-82-3	39	129.6 ± 22.9	No Standard
Methane, diethoxy-Cyclohexane	462-95-3	3	330.0	No Standard

[a] Average ± standard error.

Table 3.1 Reagents Used in Column Test

Reagent	Source
Water - ASTM Type I, provided by a Barnstead 18megohm water purification system	Nanopure Infinity
NH_4Cl - USP Grade	Fisher
$CaSO_4$ - ACS Grade	MP Biochemicals
KNO_3 - ACS Grade	Fisher
$NaNO_3$ - ACS Grade	Fisher
$Mg(NO_3)_2$ - ACS Grade	Fisher
Simulated Rainwater (pH 4.2)	Prepared by the method of Serkiz, et. al. 1999 (*5*)

Table 3.2 Selected SVOCs and CASRN

Name	CASRN
Aniline	62-53-3
Phenol	108-95-2
2,4-Dimethylphenol	105-67-9
Benzothiazole	95-16-9
Dicyclohexylamine	101-83-7
2-Hydroxybenzothiazole	934-34-9
Phthalimide	85-41-6
Formaldehyde Diethyl Acetal	462-95-3
Cyclohexyl Isothiocyanate	1122-82-3
2-Mercaptobenzothiazole	149-30-4

Table 3.3 Summary of Column Test Results for Zinc and Detected SVOCs

Analytes	Average Concentration[a] (μg/L)		Groundwater Standard/ Guidance Value (μg/L)
	Facility #1 Truck/Ambient	Facility #4 Mixed/Cryogenic	
Zinc	291.9 ± 72.0	214.1 ± 80.3	2000
Aniline	37.5 ± 7.4	21.5 ± 2.2	5
Phenol	0.7 ± 0.1	1.4 ± 0.2	1
Benzothiazole	215.3 ± 25.1	92.7 ± 6.3	No Standard
Phthalimide	107.5 ± 28.7	23.0 ± 2.5	No Standard

[a] Average ± standard error.

Table 4.1 Surface Runoff Test Results for VOCs

Analyte	CASRN	Concentration (μg/L)
1,1,1-Trichloroethane	71-55-6	< 1
1,1,2,2-Tetrachloroethane	79-34-5	< 1
1,1,2-Trichloroethane	79-00-5	< 1
1,1-Dichloroethane	75-34-3	< 1
1,1-Dichloroethene	75-35-4	< 1
1,2-Dichlorobenzene	95-50-1	< 1
1,2-Dichloroethane	107-06-2	< 1
1,2-Dichloropropane	78-87-5	< 1
1,3-Dichlorobenzene	541-73-1	< 1
1,4-Dichlorobenzene	106-46-7	< 1
2-Chloroethylvinyl ether	110-75-8	< 1
Benzene	71-43-2	< 1
Bromodichloromethane	75-27-4	< 1
Bromoform	75-25-2	< 1
Bromomethane	74-83-9	< 1
Carbon tetrachloride	56-23-5	< 1
Chlorobenzene	108-90-7	< 1
Chloroethane	75-00-3	< 1
Chloroform	67-66-3	< 1
Chloromethane	74-87-3	< 1
cis-1,3-Dichloropropene	10061-01-5	< 1
Dibromochloromethane	124-48-1	< 1
Ethylbenzene	100-41-4	< 1
Methylene chloride	75-09-2	< 1
Tetrachloroethene	127-18-4	< 1
Toluene	108-88-3	< 1
trans-1,2-Dichloroethene	156-60-5	< 1
trans-1,3-Dichloropropene	10061-02-6	< 1
Trichloroethene	79-01-6	< 1
Trichlorofluoromethane	75-69-4	< 1
Vinyl chloride	75-01-4	< 1

Table 4.2 Surface Runoff Test Results for SVOCs

Analyte	CASRN	Concentration (μg/L)
1,2,4-Trichlorobenzene	120-82-1	< 5
1,2-Dichlorobenzene	95-50-1	< 5
1,3-Dichlorobenzene	541-73-1	< 5
1,4-Dichlorobenzene	106-46-7	< 5
2,2´-oxybis(1-Chloropropane)	108-60-1	< 5
2,4,6-Trichlorophenol	88-06-2	< 5
2,4-Dichlorophenol	120-83-2	< 5
2,4-Dimethylphenol	105-67-9	< 5
2,4-Dinitrophenol	51-28-5	< 10
2,4-Dinitrotoluene	121-14-2	< 5
2,6-Dinitrotoluene	606-20-2	< 5
2-Chloronaphthalene	91-58-7	< 5
2-Chlorophenol	95-57-8	< 5
2-Nitrophenol	88-75-5	< 5
3,3´-Dichlorobenzidine	91-94-1	< 5
4,6-Dinitro-2-methylphenol	534-52-1	< 10
4-Bromophenyl-phenylether	101-55-3	< 5
4-Chloro-3-methylphenol	59-50-7	< 5
4-Chlorophenyl-phenylether	7005-72-3	< 5
4-Nitrophenol	100-02-7	< 10
Acenaphthene	83-32-9	< 5
Acenaphthylene	208-96-8	< 5
Anthracene	120-12-7	< 5
Benzidine	92-87-5	< 50
Benzo(a)anthracene	56-55-3	< 5
Benzo(a)pyrene	50-32-8	< 5
Benzo(b)fluoranthene	205-99-2	< 5
Benzo(g,h,i)perylene	191-24-2	< 5
Benzo(k)fluoranthene	207-08-9	< 5
Bis(2-chloroethoxy)methane	111-91-1	< 5
Bis(2-chloroethyl)ether	111-44-4	< 5
Bis(2-ethylhexyl)phthalate	117-81-7	< 5
Butyl benzyl phthalate	85-68-7	< 5
Chrysene	218-01-9	< 5
Dibenzo(a,h)anthracene	53-70-3	< 5
Diethylphthalate	84-66-2	< 5
Dimethylphthalate	131-11-3	< 5
Di-n-butyl phthalate	84-74-2	< 5
Di-n-octyl phthalate	117-84-0	< 5
Fluoranthene	206-44-0	< 5
Fluorene	86-73-7	< 5

Analyte	CASRN	Concentration (μg/L)
Hexachlorobenzene	118-74-1	< 5
Hexachlorobutadiene	87-68-3	< 5
Hexachlorocyclopentadiene	77-47-4	< 5
Hexachloroethane	67-72-1	< 5
Indeno(1,2,3-cd)pyrene	193-39-5	< 5
Isophorone	78-59-1	< 5
Naphthalene	91-20-3	< 5
Nitrobenzene	98-95-3	< 5
N-Nitrosodimethylamine	62-75-9	< 5
N-Nitroso-di-n-propylamine	621-64-7	< 5
N-Nitrosodiphenylamine	86-30-6	< 5
Pentachlorophenol	87-86-5	< 5
Phenanthrene	85-01-8	< 5
Phenol	108-95-2	< 5
Pyrene	129-00-0	< 5
2(3H)-Furanone, dihydro-4-hydroxy- [a]	5469-16-9	2

[a] Tentatively identified compound – reported based on presumptive evidence and reported as estimated concentration

Table 4.3 Surface Runoff Test Results for Metals [a]

Analyte	CASRN	Concentration (μg/L)	Surface water standard [b] (μg/L)
Antimony	7440-36-0	< 2.3	3
Arsenic	7440-38-2	< 1.8	50
Beryllium	7440-41-7	< 0.096	1100
Cadmium	7440-43-9	< 0.35	5
Chromium	7440-47-3	2.2	50
Copper	7440-50-8	5.4	200
Lead	7440-92-1	1.7	50
Mercury	7440-97-6	< 0.13	0.7
Nickel	7440-02-0	8.8	100
Selenium	7440-49-2	< 1.9	10
Silver	7440-22-4	< 0.54	50
Thallium	7440-28-0	< 1.9	8
Zinc	7440-66-6	59.5	82.6

[a] Results based on one sample collected
[b] Assume water hardness = 100 ppm

Table 4.4 Groundwater Field Information

Turf Field #	Turf Field Area (ft^2)	Depth to groundwater (ft)	Age of Field	# Samples	# Wells
1	531,000	68.5 - 70.0	4-5 years	6	2
2	120,000	11.3 - 12.0	< 1 year	8	2
3	82,300	36.8 - 38.0	4-7 years	10	3
4	77,400	8.3 - 8.9	2-4 years	8	2

Table 4.5 Groundwater Test Results for Selected SVOCs

Analyte	CASRN	Concentration (μg/L)
Aniline	62-53-3	< 0.39
Phenol	108-95-2	< 0.59
Benzothiazole	95-16-9	< 0.83

Table 4.6 Groundwater Test Results for all SVOCs

Analyte	CASRN	Concentration (μg/L)
Acenaphthene	83-32-9	< 0.38
Acenaphthylene	208-96-8	< 0.72
Aniline	62-53-3	< 0.39
Anthracene	120-12-7	< 0.5
Benz(a)anthracene	56-55-3	< 0.24
Benzo(a)pyrene	50-32-8	< 0.5
Benzo(b)fluoranthene	205-99-2	< 0.36
Benzo(g,h,i)perylene	191-24-2	< 0.3
Benzo(k)fluoranthene	207-08-9	< 0.33
Benzothiazole	95-16-9	< 0.83
Benzyl Alcohol	100-51-6	< 0.55
Butyl Benzyl Phthalate	85-68-7	< 0.64
Di-n-butyl Phthalate	84-74-2	< 0.65
Carbazole	86-74-8	< 0.42
Indeno(1,2,3-cd)pyrene	193-39-5	< 0.44
4-Chloroaniline	106-47-8	< 0.63
Bis(2-chloroethoxy)methane	111-91-1	< 0.66
Bis(2-chloroethyl) Ether	111-44-4	< 0.63
2-Chloronaphthalene	91-58-7	< 0.66
2-Chlorophenol	95-57-8	< 0.32
Bis(1-chloroisopropyl) Ether	108-60-1	< 0.67
Chrysene	218-01-9	< 0.6
Dibenz(a,h)anthracene	53-70-3	< 0.32
Dibenzofuran	132-64-9	< 0.49
1,3-Dichlorobenzene	541-73-1	< 0.6
1,2-Dichlorobenzene	95-50-1	< 0.86
1,4-Dichlorobenzene	106-46-7	< 0.28

Analyte	CASRN	Concentration (μg/L)
3,3'-Dichlorobenzidine	91-94-1	< 0.46
2,4-Dichlorophenol	120-83-2	< 0.59
Diethyl Phthalate	84-66-2	< 0.55
Dimethyl Phthalate	131-11-3	< 0.7
2,4-Dimethylphenol	105-67-9	< 1.6
2,4-Dinitrophenol	51-28-5	< 21
2,4-Dinitrotoluene	121-14-2	< 0.68
2,6-Dinitrotoluene	606-20-2	< 0.75
Bis(2-ethylhexyl) Phthalate	117-81-7	< 0.27
Fluoranthene	206-44-0	< 0.44
Fluorene	86-73-7	< 0.55
Hexachlorobenzene	118-74-1	< 0.42
Hexachlorobutadiene	87-68-3	< 0.6
Hexachlorocyclopentadiene	77-47-4	< 0.53
Hexachloroethane	67-72-1	< 0.7
Isophorone	78-59-1	< 0.56
2-Methylnaphthalene	91-57-6	< 0.42
4,6-Dinitro-2-methylphenol	534-52-1	< 0.86
4-Chloro-3-methylphenol	59-50-7	< 0.72
2-Methylphenol	95-48-7	< 0.54
4-Methylphenol	106-44-5	< 0.78
Naphthalene	91-20-3	< 0.49
2-Nitroaniline	88-74-4	< 14
3-Nitroaniline	99-09-2	< 9.3
4-Nitroaniline	100-01-6	< 10
Nitrobenzene	98-95-3	< 0.59
2-Nitrophenol	88-75-5	< 0.76
4-Nitrophenol	100-02-7	< 6.2
N-Nitrosodimethylamine	62-75-9	< 0.43
N-Nitrosodiphenylamine	86-30-6	< 0.47
Di-n-octyl Phthalate	117-84-0	< 0.63
Pentachlorophenol (PCP)	87-86-5	< 16
Phenanthrene	85-01-8	< 0.31
Phenol	108-95-2	< 0.59
4-Bromophenyl Phenyl Ether	101-55-3	< 0.67
4-Chlorophenyl Phenyl Ether	7005-72-3	< 0.4
N-Nitrosodi-n-propylamine	621-64-7	< 0.37
Pyrene	129-00-0	< 0.44
1,2,4-Trichlorobenzene	120-82-1	< 0.62
2,4,6-Trichlorophenol	88-06-2	< 0.43
2,4,5-Trichlorophenol	95-95-4	< 0.55

Table 5.1 Predicted Groundwater Concentrations for Crumb Rubber Derived from Truck and Mixed Tires Using a Dilution Attenuation Factor (DAF) of 100 for Organics.

Compound	Groundwater Quality Standards/ Guidance Values (µg/L)	Facility#1 Truck Tires		Facility #4 Mixed Tires	
		SPLP [a] (µg/L)	GW Conc. (µg/L)	SPLP [a] (µg/L)	GW Conc. (µg/L)
Aniline	5	347	3.5	124	1.2
Phenol	1	6	0.1	23	0.2
Benzothiazole	No Standard [b]	1,062	10.1	394	3.9
Zinc[c]	2000	7,700	192.5	1,400	35.0

[a] 95% Upper Confidence Limit
[b] Unspecified Organic Compound (UOC) standard of 50 µg/L is used for comparison purposes
[c] NYSDEC uses a DAF of 40 for metals.

Table 6.1 Surface Water Standards for Compounds of Concern

Compound	Facility #1 Truck Tires		Facility #4 Mixed Tires		Surface Water Standard (µg/L) for Stream Classes B, C, D
	SPLP Test [a]	Column Test [a]	SPLP Test [a]	Column Test [a]	
Zinc	7,700	436	1,400	375	117.2/82.6 [b]
Phenol	6	1	23	2	5
Aniline	347	52	124	26	No Standard
Benzothiazole	1,062	265	394	105	No Standard

[a] 95% Upper Confidence Limit
[b] For acute and chronic water quality standards for zinc, respectively, assuming hardness = 100 ppm. See Appendix E1 for calculations of surface water standards.

Table 7.1 Sampling Locations

Sampling Location	Sampling Height	Duplicate Sample
Upwind edge of field	3 feet	Yes
On field in shade	0.4-0.8 inches & 3 feet	No
On field in center	0.4-0.8 inches , 3 feet, 6 feet	No
Downwind edge of field	0.4-0.8 inches , 3 feet, 6 feet	Yes at 3 foot height

Table 7.2 Modifications to Method TO-13A

Requirement	TO-13A	ATL Modifications
Extraction Solvent	10% ether in hexane for PUF; methylene chloride (DCM) for XAD sorbent. Final extract in hexane.	DCM for PUF/XAD cartridge and XAD sorbent. Final extract in DCM.
Glassware Cleaning	Muffle furnace is utilized.	Solvent cleaning procedure is used.
Extraction technique	Soxhlet extraction	Soxhlet extraction or pressurized fluid extraction (PFE).
Calibration range	0.10 to 2.5 µg/mL	1.0 µg/mL to 160 µg/mL
Field surrogates	Deuterated polycyclic aromatic hydrocarbons (PAHs) are spiked on media prior to sampling.	Performed by client request only.
Solvent Process Blank	Required each analytical batch.	Not performed; each solvent lot is certified prior to use.
Method Blank	<Method Detection Limit	<Reporting Limit

Table 8.1 Chemicals Detected in Air Samples Collected at the Thomas Jefferson Field* Concentrations are μg/m^3

CHEMICAL NAME	Upwind of field @ 3 feet above surface	On-field in shade @ surface	On-field in shade @ 3 feet above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 feet above surface	Center of field in the sun @ 6 feet above surface	Downwind of field @ surface	Downwind of field @ 3 feet above surface	Downwind of field @ 6 feet above surface
1,2,4-Trimethylbenzene	0.28	0.22	0.17	0.17	0.16	0.16	0.11	0.17	0.098
1,4-Dichlorobenzene	0.12	0.18	0.12	0.15	0.12	0.14	0.092	0.13	0.1
4-Methyl-2-pentanone	ND	ND	ND	1.2	ND	ND	ND	ND	ND
Acetone	0.48	0.48	ND	ND	ND	ND	ND	ND	ND
Benzene	0.4	0.4	0.44	ND	0.48	0.54	0.37	0.41	0.27
Carbon Tetrachloride	0.27	0.26	0.34	0.29	0.26	0.34	0.3	0.31	0.23
Chloroform	ND	0.1	0.15	ND	ND	0.14	ND	0.084	ND
Ethyl Benzene	0.23	0.18	0.18	0.18	0.16	0.17	0.14	0.19	0.11
Freon 11	0.34	0.22	0.69	0.33	0.31	0.52	0.37	0.4	0.3
Freon 113	0.085	ND	0.13	0.095	ND	0.12	0.087	0.1	ND
Freon 12	0.81	0.39	1.1	0.74	0.68	1	0.77	0.79	0.7
Hexane	0.44	0.36	0.4	ND	0.29	0.34	0.33	0.32	0.3
m,p-Xylene	0.72	0.56	0.54	0.52	0.5	0.5	0.38	0.52	0.32
Methylene Chloride	0.11	ND	0.17	0.16	0.13	0.16	0.29	0.096	0.099
o-Xylene	0.26	0.22	0.19	0.17	0.18	0.17	0.13	0.19	0.1
Tetrachloroethene	0.28	0.34	0.3	0.3	0.26	0.29	0.27	0.29	0.2
Toluene	1.5	1.4	1.3	1.3	1.2	1.4	1.1	1.3	0.82
1,2-Butadiene, 3-methyl-	-	-	-	-	0.42 J (81%)	-	-	-	-
1,3-Butadiene, 2-methyl-	-	-	0.89 J (81%)	-	-	-	-	-	-
1,3-Pentadiene	0.46 J (94%)	0.51 J (94%)	-	-	-	1.1 J (94%)	0.53 J (91%)	0.58 J (94%)	-
1,3-Pentadiene, (E)-	-	-	-	-	-	-	-	0.62 J (90%)	-
1,3-Pentadiene, (Z)-	0.48 J (83%)	-	-	0.64 J (96%)	-	-	-	-	-
1,4-Pentadiene	-	-	-	-	-	-	-	-	0.52 J

CHEMICAL NAME	Upwind of field @ 3 feet above surface	On-field in shade @ surface	On-field in shade @ 3 feet above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 feet above surface	Center of field in the sun @ 6 feet above surface	Downwind of field @ surface	Downwind of field @ 3 feet above surface	Downwind of field @ 6 feet above surface
									(93%)
1H-Benzotriazol-5-amine, 1-methyl-	-	-	-	-	-	9.2 J (47%)	8.5 J (43%)	13 J (32%)	9.1 J (43%)
1-Heptene	-	-	-	1 J (49%)	-	-	-	-	-
1-Iodo-2-methylundecane	-	-	-	0.76 J (72%)	-	-	-	-	-
2-Dibenzofuranamine	-	-	11 J (38%)	-	-	-	-	-	-
2-Hexen-1-ol, (Z)-	-	-	-	-	-	-	-	-	22 J (43%)
2-Octen-1-ol, (E)-	-	0.64 J (35%)	-	-	-	-	-	-	-
3-Dibenzofuranamine	-	-	-	-	-	-	-	8.6 J (38%)	-
4-Dibenzofuranamine	-	-	-	8.4 J (46%)	-	8.6 J (50%)	-	8.7 J (38%)	-
5-Hexen-2-ol, (.+/-.)-	-	-	-	-	-	-	24 J (40%)	-	-
Benzene, 1-ethyl-2-methyl-	0.64 J (76%)	-	-	-	-	-	-	-	-
Benzene, 1-ethyl-4-methyl-	0.41 J (70%)	0.67 J (91%)	0.54 J (76%)	-	0.52 J (93%)	0.43 J (76%)	0.42 J (76%)	0.55 J (80%)	0.33 J (70%)
Benzenemethanol, ar-ethenyl-	-	-	10 J (62%)	-	13 J (68%)	-	-	8.9 J (52%)	-
Butane	-	-	-	-	-	0.45 J (64%)	0.3 J (64%)	-	-
Butane, 2-methyl-	-	-	0.48 J (86%)	0.32 J (80%)	-	-	0.34 J (80%)	0.29 J (80%)	0.26 J (80%)
Cyclohexanol	23 J (32%)	-	-	21 J (22%)	19 J (22%)	27 J (16%)	-	23 J (46%)	-
Cyclopentane	-	-	-	-	-	-	0.3 J (78%)	-	-
Cyclopentanone, 2-	10 J (72%)	-	-	-	-	10 J (53%)	-	-	-

CHEMICAL NAME	Upwind of field @ 3 feet above surface	On-field in shade @ surface	On-field in shade @ 3 feet above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 feet above surface	Center of field in the sun @ 6 feet above surface	Downwind of field @ surface	Downwind of field @ 3 feet above surface	Downwind of field @ 6 feet above surface
methyl-									
Decanal	-	-	-	0.46 J (90%)	-	-	-	-	-
Decane	1.2 J (53%)	-	1.2 J (64%)	1.4 J (87%)	1.2 J (64%)	1.3 J (64%)	1 J (64%)	1.3 J (64%)	0.93 J (64%)
Decane, 2,5,6-trimethyl-	0.89 J (42%)	-	-	-	-	-	-	-	-
Decane, 2,9-dimethyl-	-	1.4 J (64%)	-	-	-	-	-	-	-
Decane, 5-methyl-	0.28 J (50%)	-	-	-	-	-	-	-	-
Decane, 6-ethyl-2-methyl-	-	-	-	-	-	-	-	1.2 J (64%)	-
Dodecanal	0.38 J (72%)	-	-	-	-	-	-	0.37 J (59%)	-
Heptane	0.31 J (91%)	0.43 J (86%)	-	0.36 J (74%)	-	-	-	0.3 J (87%)	-
Heptane, 2,3,4-trimethyl-	-	-	0.38 J (50%)	-	-	-	-	-	-
Hexane, 3-methyl-	0.29 J (87%)	-	-	-	-	-	-	-	-
Methanimidamide, N,N-dimethyl-N'-phenyl-	-	-	-	-	9.6 J (72%)	-	-	-	-
Nonanal	0.59 J (72%)	0.88 J (58%)	0.54 J (56%)	-	0.76 J (72%)	-	0.5 J (64%)	0.75 J (59%)	0.34 J (53%)
Nonanamide	-	-	-	-	-	13 J (50%)	-	-	-
Nonane	1.1 J (72%)	1.4 J (45%)	1 J (76%)	1 J (90%)	0.99 J (70%)	2.5 J (90%)	0.81 J (47%)	0.99 J (66%)	2.3 J (91%)
Octane, 2-methyl-	-	-	-	-	-	-	-	-	0.26 J

CHEMICAL NAME	Upwind of field @ 3 feet above surface	On-field in shade @ surface	On-field in shade @ 3 feet above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 feet above surface	Center of field in the sun @ 6 feet above surface	Downwind of field @ surface	Downwind of field @ 3 feet above surface	Downwind of field @ 6 feet above surface
									(72%)
Pentadecane	0.46 J (90%)	-	-	-	-	-	-	-	-
Pentanamide, 4-methyl-	-	-	-	-	15 J (50%)	-	-	-	-
Pentane, 2,2,3,4-tetramethyl-	-	-	-	-	0.31 J (72%)	-	-	-	-
Pentane, 2-methyl-	0.4 J (91%)	-	-	-	-	-	-	0.28 J (90%)	-
Propane, 2-methyl-	-	-	0.4 J (4%)	-	-	-	-	-	-
Tetradecane, 1-chloro-	-	-	-	-	-	0.42 J (74%)	-	-	-
Undecane	0.51 J (91%)	0.58 J (90%)	0.42 J (91%)	-	0.49 J (90%)	0.45 J (81%)	0.41 J (76%)	0.49 J (91%)	0.33 J (81%)
Undecane, 2,6-dimethyl-	-	-	-	-	-	-	-	-	0.26 J (50%)
Undecane, 3-methyl-	1.1 J (53%)	-	-	-	-	-	-	-	-
Undecane, 5,6-dimethyl-	-	-	-	-	-	-	-	0.34 J (50%)	-

ND = not detected
J = estimated concentration of a tentatively identified compound (TIC)
- = not reported
(%) = match quality
* Chemicals that did not meet the laboratory/field blank criterion are not included.

Table 8.2 Chemicals Detected in Air Samples Collected at the John Mullaly Field* Concentrations are μg/m^3.

CHEMICAL NAME	Upwind of field @ 3 feet above surface	On-field in shade @ surface	On-field in shade @ 3 feet above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 feet above surface	Center of field in the sun @ 6 feet above surface	Downwind of field @ surface	Downwind of field @ 3 feet above surface	Downwind of field @ 6 feet above surface
1,2,4-Trimethylbenzene	0.26	0.26	0.24	0.19	0.10	0.21	0.22	0.27	0.22
1,3,5-Trimethylbenzene	0.089	ND	ND	ND	ND	ND	ND	ND	ND
1,4-Dichlorobenzene	0.46	0.52	0.49	0.40	0.24	0.41	0.46	0.55	0.48
4-Methyl-2-pentanone	ND	0.78	ND	0.67	ND	ND	ND	ND	ND
Acetone	ND	0.55	0.55	ND	0.56	0.53	ND	ND	ND
Benzene	0.39	0.34	0.35	0.14	ND	0.22	0.33	ND	0.35
Benzothiazole	ND	ND	ND	6.5	ND	ND	ND	ND	ND
Carbon Tetrachloride	0.26	0.33	0.34	0.14	ND	0.19	0.34	0.2	0.32
Chloroform	ND	0.096	0.092	ND	ND	ND	0.15	0.087	0.087
Chloromethane	ND	0.10	ND	ND	ND	ND	0.10	ND	0.11
Ethyl Benzene	0.29	0.28	0.28	0.18	0.11	0.24	0.24	0.27	0.27
Freon 11	0.4	0.62	0.69	0.20	0.16	0.26	0.56	0.44	0.70
Freon 113	0.092	0.22	0.20	ND	ND	ND	0.16	0.13	0.14
Freon 12	0.74	1.0	1.0	0.32	0.24	0.43	1.0	0.85	1.1
Hexane	0.38	0.35	0.37	0.12	ND	0.16	0.37	0.32	0.41
m,p-Xylene	0.83	0.82	0.80	0.55	0.33	0.71	0.72	0.80	0.80
Methylene Chloride	0.19	2.3	0.81	0.95	ND	0.12	3.0	0.35	0.17
o-Xylene	0.26	0.28	0.27	0.16	0.088	0.21	0.22	0.27	0.24
Tetrachloroethene	1.2	1.2	1.2	0.74	0.38	0.91	0.88	0.84	0.83
Toluene	1.4	1.3	1.5	0.72	0.43	1.3	1.0	0.75	1.6
1,3-Butadiene, 2-methyl-	-	-	-	-	-	0.23 J (94%)	-	-	-
1,3-Pentadiene	-	0.52 J (96%)	0.51 J (94%)	-	-	-	0.53 J (94%)	0.44 J (95%)	0.45 J (94%)
1-Butanol, 4-methoxy-	50 J (23%)	-	-	-	-	-	-	-	-

CHEMICAL NAME	Upwind of field @ 3 feet above surface	On-field in shade @ surface	On-field in shade @ 3 feet above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 feet above surface	Center of field in the sun @ 6 feet above surface	Downwind of field @ surface	Downwind of field @ 3 feet above surface	Downwind of field @ 6 feet above surface
1-Hexene, 3,4,5-trimethyl-	1.5 J (59%)	0.45 J (59%)	-	-	-	-	-	-	-
1-Hexene, 4,5-dimethyl-	-	-	-	-	-	-	0.33 J (64%)	-	-
1-Propene, 2-methyl-	-	-	-	0.46 J (80%)	0.33 J (80%)	1.0 J (50%)	-	-	-
2-Butene, (E)-	-	1.8 J (52%)	-	-	-	0.54 J (80%)	-	0.56 J (59%)	-
2-Butene, (Z)-	2.8 J (50%)	-	2.7 J (50%)	0.55 J (64%)	0.23 J (59%)	-	0.88 J (42%)	-	1.1 J (53%)
2-Dibenzofuranamine	-	-	-	-	-	-	-	12 J (38%)	-
3-Dibenzofuranamine	-	10 J (38%)	-	-	-	-	11 J (38%)	9.9 J (38%)	-
3H-Indazol-3-one, 1,2-dihydro-2-methyl-	14 J (53%)	-	-	-	-	-	-	-	12 J (53%)
4-Dibenzofuranamine	9.0 J (46%)	-	-	10 J (44%)	8.9 J (43%)	9.1 J (35%)	-	-	11 J (43%)
Benzaldehyde, ethyl-	-	9.6 J (91%)	-	-	-	-	-	-	-
Benzene, 1,3-dimethyl-	9.2 J (53%)	-	-	-	-	-	-	-	-
Benzene, 1-ethyl-2-methyl-	1.8 J (80%)	-	-	-	-	-	-	0.59 J (86%)	0.51 J (55%)
Benzene, 1-ethyl-3-methyl-	-	-	0.51 J (55%)	-	-	-	-	-	-
Benzene, 1-ethyl-4-methyl-	0.48 J (60%)	0.56 J (87%)	-	-	-	-	0.49 J (86%)	-	-
Benzene, 1-methoxy-4-(1-propenyl)-	-	-	-	-	9.9 J (52%)	-	9.7 J (45%)	-	-

CHEMICAL NAME	Upwind of field @ 3 feet above surface	On-field in shade @ surface	On-field in shade @ 3 feet above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 feet above surface	Center of field in the sun @ 6 feet above surface	Downwind of field @ surface	Downwind of field @ 3 feet above surface	Downwind of field @ 6 feet above surface
Benzene, 2-methoxy-1,3,4-trimethyl-	-	-	-	2.1 J (17%)	-	-	-	-	-
Benzo[b]thiophene, 6-methyl-	-	-	-	-	-	8.7 J (53%)	-	-	-
Butane	-	0.50 J (38%)	0.43 J (38%)	-	-	-	0.42 J (52%)	0.33 J (56%)	0.41 J (64%)
Butane, 2-iodo-2-methyl-	0.34 J (72%)	-	-	-	-	0.35 J (64%)	-	-	-
Butane, 2-methyl-	0.42 J (80%)	0.65 J (80%)	0.61 J (80%)	0.22 J (80%)	-	-	0.50 J (80%)	0.31 J (80%)	0.42 J (80%)
Cycloheptane	-	-	-	-	-	-	-	0.23 J (27%)	-
Cyclohexane, 1,1,3-trimethyl-	-	-	0.60 J (86%)	-	-	-	-	-	-
Cyclohexane, 1,3-dimethyl-, cis	0.94 J (94%)	-	-	-	-	0.47 J (95%)	0.44 J (95%)	0.42 J (94%)	0.48 J (94%)
Cyclohexane, 1,4-dimethyl-	-	-	1.1 J (91%)	-	-	-	-	-	-
Cyclohexane, ethyl-	1 J (87%)	1.3 J (64%)	-	0.38 J (87%)	-	0.55 J (90%)	0.47 J (68%)	0.52 J (86%)	0.59 J (90%)
Cyclopropane, 1-chloro-2-ethenyl-1-methy	-	-	17 J (59%)	-	-	-	23 J (64%)	18 J (59%)	-
Decane	3.3 J (53%)	1.1 J (64%)	-	-	0.64 J (64%)	-	1.1 J (59%)	1.2 J (64%)	1.1 J (64%)
Decane, 2,3,8-trimethyl-	1.5 J (53%)	-	-	-	-	-	-	-	-
Decane, 2,9-dimethyl-	-	-	-	0.92 J (59%)	-	-	-	-	-
Dodecane, 2,6,11-	0.66 J	-	-	0.23 J	-	-	-	-	-

CHEMICAL NAME	Upwind of field @ 3 feet above surface	On-field in shade @ surface	On-field in shade @ 3 feet above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 feet above surface	Center of field in the sun @ 6 feet above surface	Downwind of field @ surface	Downwind of field @ 3 feet above surface	Downwind of field @ 6 feet above surface
trimethyl-	(78%)			(78%)					
Dodecane, 2,7,10-trimethyl-	-	-	-	-	-	-	0.36 J (78%)	-	-
Ethane, 1,1,2,2-tetrachloro-	12 J (95%)	-	-	-	-	-	-	-	-
Heptane	0.42 J (91%)	-	-	0.23 J (91%)	-	0.32 J (91%)	-	0.30 J (80%)	-
Heptane, 2,2-dimethyl-	-	0.51 J (64%)	-	-	-	-	-	-	-
Heptane, 2,4-dimethyl-	1.5 J (86%)	1.5 J (78%)	-	-	-	0.85 J (78%)	0.62 J (86%)	0.76 J (64%)	-
Heptane, 2,5-dimethyl-	0.82 J (68%)	0.72 J (68%)	0.77 J (68%)	-	-	-	-	-	-
Heptane, 2,6-dimethyl-	-	-	1.6 J (72%)	-	0.37 J (59%)	-	-	-	-
Heptane, 2-methyl-	0.98 J (72%)	0.76 J (53%)	1.0 J (80%)	0.32 J (64%)	-	0.68 J (86%)	-	-	0.62 J (50%)
Heptane, 3-methyl-	0.45 J (83%)	0.49 J (72%)	0.62 J (83%)	-	-	0.38 J (83%)	-	-	0.36 J (72%)
Heptane, 4-(1-methylethyl)-	-	-	-	0.30 J (64%)	-	-	-	-	-
Heptane, 4-ethyl-2,2,6,6-tetramethyl-	-	-	-	-	-	0.54 J (56%)	-	-	-
Hexane, 2,2,4-trimethyl-	0.61 J (64%)	-	-	-	-	-	-	-	-
Hexane, 2,2,5-trimethyl-	2.1 J (72%)	-	0.51 J (72%)	-	-	-	0.47 J (72%)	0.60 J (72%)	0.47 J (72%)
Hexane, 3,3-dimethyl-	0.44 J (59%)	-	-	-	-	-	-	-	-

CHEMICAL NAME	Upwind of field @ 3 feet above surface	On-field in shade @ surface	On-field in shade @ 3 feet above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 feet above surface	Center of field in the sun @ 6 feet above surface	Downwind of field @ surface	Downwind of field @ 3 feet above surface	Downwind of field @ 6 feet above surface
Hydroxylamine, O-decyl-	-	-	-	-	-	-	-	-	0.88 J (64%)
Methanimidamide, N,N-dimethyl-N'-phenyl-	16 J (50%)	-	-	8.7 J (50%)	-	-	-	-	-
Nonanal	1.28 J (68%)	-	0.54 J (72%)	0.47 J (50%)	0.45 J (72%)	0.51 J (78%)	-	-	0.42 J (53%)
Nonane	3.2 J (91%)	2.6 J (91%)	3.2 J (91%)	2.1 J (87%)	1.7 J (87%)	2.8 J (94%)	1.8 J (91%)	2.3 J (91%)	2.7 J (83%)
Nonane, 3-methyl-5-propyl-	-	-	-	-	-	-	-	0.33 J (72%)	-
Octane	6.3 J (90%)	4.5 J (45%)	6.2 J (46%)	3.4 J (74%)	3.0 J (49%)	5.9 J (94%)	3.1 J (70%)	4.7 J (38%)	6.0 J (76%)
Octane, 2-methyl-	-	-	0.41 J (72%)	-	-	-	-	-	-
Octane, 3-methyl-	0.64 J (64%)	-	-	-	-	0.42 J (90%)	-	0.39 J (80%)	0.44 J (91%)
Pentane	-	0.46 J (86%)	0.40 J (86%)	-	-	-	-	-	-
Pentane, 2,2,3,4-tetramethyl-	-	-	-	0.42 J (53%)	0.30 J (53%)	-	-	-	-
Pentane, 2-methyl-	-	-	-	-	-	-	0.35 J (80%)	0.31 J (91%)	0.32 J (91%)
Pentane, 3,3-dimethyl-	-	-	-	-	-	0.40 J (50%)	-	0.44 J (64%)	-
Propane, 2-methyl-	-	-	-	-	-	-	-	0.25 J (45%)	-
Tetradecane, 1-chloro-	-	-	-	0.56 J (74%)	-	-	-	-	-
Tridecane	0.96 J	-	-	-	-	0.96 J	-	-	-

CHEMICAL NAME	Upwind of field @ 3 feet above surface	On-field in shade @ surface	On-field in shade @ 3 feet above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 feet above surface	Center of field in the sun @ 6 feet above surface	Downwind of field @ surface	Downwind of field @ 3 feet above surface	Downwind of field @ 6 feet above surface
	(59%)					(53%)			
Undecane	2.2 J (80%)	0.93 J (90%)	0.95 J (91%)	0.78 J (91%)	0.65 J (83%)	0.79 J (87%)	0.91 J (90%)	1.0 J (90%)	0.77 J (90%)
Undecane, 4,6-dimethyl-	-	-	-	0.23 J (64%)	-	-	-	-	-
Undecane, 4-methyl-	-	-	-	0.28 J (64%)	-	-	-	-	-

ND = not detected
J = estimated concentration of a tentatively identified compound (TIC)
- = not reported
(%) = match quality
* Chemicals that did not meet the laboratory/field blank criterion are not included.

Table 8.3 TICs Detected in Laboratory and/or Field Blank Samples. Concentrations are μg/m^3

Tentatively Identified Compound	Laboratory Blank Concentration		Field Blank Concentration	
	Thomas Jefferson Field	John Mullaly Field	Thomas Jefferson Field	John Mullaly Field
2-Cyclohexen-1-ol	32J	34J	38J	40J
2-Cyclohexen-1-one	33J	35J	35J	42J
7-Oxabicyclo[4.1.0]heptane	35J	25J	32J	30J
Benzene, 1-methoxy-4-(1-propenyl)-	NR	12J	NR	NR
Benzene, 2,4-diisocyanato-1-methyl-	13J	15J	9.1J	10J
Bi-2-cyclohexen-1-yl	24J	NR	18J	NR
Cyclohexanol	18J	15J	NR	18J
Cyclohexanol, 2-chloro-, trans-	21J	30J	20J	33J
Cyclopentene, 1,5-dimethyl-	NR	12J	NR	15J
Cyclohexanone	NR	NR	9.2J	NR
Benzene, 1,2-dimethyl-	NR	NR	NR	10J
Cyclopentanol, 2-methyl-	NR	NR	19J	NR
Tetradecane	NR	NR	NR	0.63J
Undecane, 2,3-dimethyl-	NR	NR	0.29J	NR

NR = not reported
J = estimated concentration

Table 8.4 Thomas Jefferson Field – Measured Air Concentrations (μg/m^3) for Chemicals Selected for Health Risk Evaluation

Name	Air Concentration (μg/m^3)*								
	Upwind of field @ 3 ft above surface	On-field in shade @ surface	On-field in shade @ 3 ft above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 ft above surface	Center of field in the sun @ 6 ft above surface	Downwind of field @ surface	Downwind of field @ 3 ft above surface	Downwind of field @ 6 ft above surface
Chemicals Detected in Field Survey Also Detected in DEC Laboratory Off-gassing Study									
1,4-Dichlorobenzene	0.12	0.18	0.12	0.15	0.12	0.14	0.092	0.13	0.1
4-Methyl-2-pentanone	ND	ND	ND	1.2	ND	ND	ND	ND	ND
Benzene	0.4	0.4	0.44	ND	0.48	0.54	0.37	0.41	0.27
Benzene, 1-ethyl-4-methyl-	0.41 J (70%)	0.67 J (91%)	0.54 J (76%)	-	0.52 J (93%)	0.43 J (76%)	0.42 J (76%)	0.55 J (81%)	0.33 J (70%)
Nonane	1.1 J (72%)	1.4 J (45%)	1 J (76%)	1 J (90%)	0.99 J (70%)	2.5 J (90%)	0.81 J (47%)	0.99 J (66%)	2.3 J (91%)
Chemicals on Target List Detected in Field Survey Not Included in DEC Off-gassing Study									
Freon 11	0.34	0.22	0.69	0.33	0.31	0.52	0.37	0.4	0.3
Freon 113	0.085	ND	0.13	0.095	ND	0.12	0.087	0.1	ND
Methylene Chloride	0.11	ND	0.17	0.16	0.13	0.16	0.29	0.096	0.099
Chemicals Detected in Field Survey Reported as Non-Detects in DEC Laboratory Off-gassing Study									
Chloroform	ND	0.1	0.15	ND	ND	0.14	ND	0.084	ND
Chemicals Detected in Field Survey as TICs									
1,3-Pentadiene	0.46 J (94%)	0.51 J (94%)	-	-	-	1.1 J (94%)	0.53 J (91%)	0.58 J (94%)	-
1,3-Pentadiene, (E)-	-	-	-	-	-	-	-	0.62 J (90%)	-
1,4-Pentadiene	-	-	-	-	-	-	-	-	0.52 J (93%)
Butane, 2-methyl-	-	-	0.48 J (86%)	0.32 J (80%)	-	-	0.34 J (80%)	0.29 J (80%)	0.26 J (80%)
Decanal	-	-	-	0.46 J (90%)	-	-	-	-	-
Heptane	0.31 J (91%)	0.43 J (86%)	-	0.36 J (74%)	-	-	-	0.3 J (87%)	-

*ND = not detected; - = not reported; J = estimated concentration; (percentage) = degree of statistical match between the mass spectrum of a suspect chemical and the mass spectrum of a known chemical from a computer-based “library” of mass spectra. The suspect chemical is tentatively identified as the chemical with the highest match quality. A match of 85% or higher is necessary for reliable identification (US EPA, 1999b).

Table 8.5 John Mullaly Field – Measured Air Concentrations (μg/m^3) for Chemicals Selected for Health Risk Evaluation

Name	Air Concentration (μg/m^3)*								
	Upwind of field @ 3 ft above surface	On-field in shade @ surface	On-field in shade @ 3 ft above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 ft above surface	Center of field in the sun @ 6 ft above surface	Downwind of field @ surface	Downwind of field @ 3 ft above surface	Downwind of field @ 6 ft above surface
Chemicals Detected in Field Survey Also Detected in DEC Laboratory Off-gassing Study									
4-Methyl-2-pentanone	ND	0.78	ND	0.67	ND	ND	ND	ND	ND
Benzothiazole	ND	ND	ND	6.5	ND	ND	ND	ND	ND
Acetone	ND	0.55	0.55	ND	0.56	0.53	ND	ND	ND
Chemicals on Target List Detected in Field Survey Not Included in DEC Off-gassing Study									
Freon 11	0.40	0.62	0.69	0.20	0.16	0.26	0.56	0.44	0.70
Freon 113	0.092	0.22	0.20	ND	ND	ND	0.16	0.13	0.14
Freon 12	0.74	1.0	1.0	0.32	0.24	0.43	1.0	0.85	1.1
Methylene Chloride	0.19	2.3	0.81	0.95	ND	0.12	3.0	0.35	0.17
Chemicals Detected in Field Survey Reported as Non-Detects in DEC Laboratory Off-gassing Study									
Chloroform	ND	0.096	0.092	ND	ND	ND	0.15	0.087	0.087
Chloromethane	ND	0.10	ND	ND	ND	ND	0.10	ND	0.11
Chemicals Detected in Field Survey as TICs									
1,3-Butadiene, 2-methyl-	-	-	-	-	-	0.23 J (94%)	-	-	-
1,3-Pentadiene	-	0.52 J (96%)	0.51 J (94%)	--	-	-	0.53 J (94%)	0.44 J (95%)	0.45 J (94%)
Benzaldehyde, ethyl-	-	9.6 J (91%)	-	-	-	-	-	-	-
Cyclohexane, 1,1,3-trimethyl-	-	-	0.60 J (86%)	-	-	-	-	-	-
Cyclohexane, 1,4-dimethyl-	-	-	1.1 J (91%)	-	-	-	-	-	-
Pentane	-	0.46 J (86%)	0.40 J (86%)	-	-	-	-	-	-
Pentane, 2-methyl-	-	-	-	-	-	-	0.35 J (80%)	0.31 J (91%)	0.32 J (91%)

*ND = not detected; - = not reported; J = estimated concentration; (percentage) = degree of statistical match between the mass spectrum of a suspect chemical and the mass spectrum of a known chemical from a computer-based "library" of mass spectra. The suspect chemical is tentatively identified as the chemical with the highest match quality. A match of 85% or higher is necessary for reliable identification (US EPA, 1999b)

Table 8.6 Toxicity Values for Chemicals Selected for Health Risk Evaluation.

Name (CASRN)	Basis for Toxicity Value	Surrogate Chemical (CASRN)	Rational	Reference Concentration $\mu g/m^3$ (Effect)	Air Concentration ($\mu g/m^3$) at 1×10^{-6} Risk Level	Source of Toxicity Values
Chemicals Detected in Field Survey Also Detected in DEC Laboratory Off-gassing Study						
1,4-Dichlorobenzene (106-46-7)	chemical-specific	NA	NA*	800 (increased liver weights in rats)	0.32	NYS (2006)
Acetone (67-64-1)	chemical-specific	NA	NA*	30,000 (neurological effects in humans)	none available**	NYS (2006)
Benzene (71-43-2)	chemical-specific	NA*	NA*	30 (decreased lymphocyte count in humans)	0.13	NYS (2006)
Benzene, 1-ethyl-4-methyl- (622-96-8)	surrogate-chemical	dimethyl benzenes (xylenes) (1330-20-7)	all are alkyl benzenes with substitutions at two positions of the benzene ring & differ only in the structure of one of the alkyl groups attached to benzene ring; xylenes have a peer-reviewed RfC	100 (impaired motor coordination in rats)	none available**	NYS (2006)
Benzothiazole (95-16-9)	chemical-specific	NA*	NA*	18*** (none reported)	none available**	***
4-Methyl-2-pentanone (108-10-1)	chemical specific	NA*	NA*	3000 (reduced fetal body wt, skeletal variations, & increased fetal death in mice; skeletal variations in rats	none available**	US EPA IRIS#
Nonane (111-84-2)	surrogate-chemical	hexane (110-54-3)	both are straight-chain alkanes; hexane among most potent alkanes & has a peer-reviewed RfC	700 (peripheral neuropathy in rats)	none available**	US EPA IRIS#
Chemicals on Target List Detected in Field Survey Not Included in DEC Off-gassing Study						
Freon 11 or trichloromonofluoromethane (75-69-4)	surrogate chemical	chlorodifluoro-methane (HCFC 22) (75-45-6)	all are halogenated methanes that differ only in the number of chlorines or fluorines attached to carbon atom; HCFC 22 has a peer-reviewed RfC	50,000 (increased kidney, adrenal & pituitary weights in rats)	none available**	US EPA IRIS#
Freon 12 or dichlorodifluoromethane (1275-71-8)						

Name (CASRN)	Basis for Toxicity Value	Surrogate Chemical (CASRN)	Rational	Reference Concentration $\mu g/m^3$ (Effect)	Air Concentration ($\mu g/m^3$) at 1×10^{-6} Risk Level	Source of Toxicity Values
Freon 113 or CFC-113 or 1,1,2-trichloro-1,2,2-trifluoroethane (76-13-1)	chemical-specific	NA*	NA*	190,000 (psychomotor impairment in humans)	none available**	US EPA IRIS#
Methylene Chloride (75-09-2)	chemical-specific	NA*	NA*	400 (blood carboxyhemoglobin above 2% in humans)	27	NYS (2006)
Chemicals Detected in Field Survey Reported as Non-Detects in DEC Laboratory Off-gassing Study						
Chloroform (67-66-3)	chemical-specific	NA*	NA*	50 (liver & kidney toxicity in mice)	14.8	NYS (2006)
Chloromethane (74-87-3)	chemical-specific	NA*	NA*	90 (cerebellar lesions in mice)	none available**	US EPA IRIS#
Chemicals Detected in Field Survey as TICs						
Benzaldehyde, ethyl- (53951-50-1)	surrogate-chemical	benzaldehyde (100-52-7)	both are aldehydes with a benzene ring & differ only in the ethyl group of the TIC; benzaldehyde has a peer-reviewed RfD	350**** (forestomach lesions, kidney toxicity in rats)	none available**	US EPA IRIS#
1,3-Butadiene, 2-methyl- (78-79-5)	surrogate-chemical	1,3-butadiene (106-99-0)	both are conjugated dienes & differ only in the methyl groups of the TIC; 1,3-butadiene is a highly potent chemical and has peer-reviewed toxicity values	2 (ovarian atrophy in mice)	0.03	US EPA IRIS#
Butane, 2-methyl (92046-46-3)	surrogate-chemical	hexane (110-54-3)	both are straight-chain alkanes & differ only in the methyl group attached to the carbon chain; hexane among most potent alkanes & has a peer-reviewed RfC	700 (peripheral neuropathy in rats)	none available**	US EPA IRIS#
Cyclohexane, 1,4-dimethyl- (589-90-2)	surrogate-chemical	cyclohexane (110-82-7)	all are cycloalkanes & differ only in the methyl groups attached to the cyclohexane ring of the TICs; cyclohexane has a peer-reviewed RfC	6000 (reduced pup weights in F1 and F2 generations in rats)	none available**	US EPA IRIS#
Cyclohexane, 1,1,3-trimethyl- (3073-66-3)						

Name (CASRN)	Basis for Toxicity Value	Surrogate Chemical (CASRN)	Rational	Reference Concentration μg/m^3 (Effect)	Air Concentration (μg/m^3) at 1 x 10^{-6} Risk Level	Source of Toxicity Values
Decanal (112-31-2)	surrogate-chemical	propanal (propionaldehyde) (123-38-6)	both are aldehydes & differ only in the number of carbon atoms; propanal has peer-reviewed RfC	8 (atrophy of olfactory epithelium in rats)	none available**	US EPA IRIS#
Heptane (142-82-5)	surrogate-chemical	hexane (110-54-3)	all are straight-chain alkanes; hexane among most potent alkanes & has a peer-reviewed RfC	700 (peripheral neuropathy in rats)	none available**	US EPA IRIS#
Pentane (109-66-0)						
1,3-Pentadiene (504-60-9)	surrogate-chemical	1,3-butadiene (106-99-0)	all are conjugated dienes & differ in the number of carbon atoms; 1,3-butadiene is a highly potent chemical & has peer-reviewed toxicity values	2 (ovarian atrophy in mice)	0.03	US EPA IRIS#
1,3-Pentadiene, (E)- (2004-70-8)						
1,4-Pentadiene (591-93-5)						

***** NA = not applicable.

****** Chemicals may lack an estimate of the air concentration associated with a lifetime excess risk of one per million (1 x 10^{-6}), assuming continuous exposure, for several different reasons: because their potency to cause cancer has not been studied, because studies of their carcinogenic potency did not show a concentration-related increase in cancer incidence or because some evidence of carcinogenic potency has been observed, but the quality of the studies or the data do not allow quantitative estimation of the 1 x 10^{-6} air concentration.

*** Reference Concentration = [Reference dose (RfD) x Adult Body Weight]/Adult Inhalation Rate: RfC = [5 μg/kg-day x 70 kg]/20 m^3/day = 18 μg /m^3, where the draft reference dose is derived from a no-observed-effect level of 5 μg /kg-day in a 90-day study with rats (WHO, 2003) and the application of a 1000-fold uncertainty factor to compensate for interspecies difference, human variation, and the use of a subchronic study to estimate a chronic reference dose.

**** Reference Concentration = [Reference dose (RfD) x Adult Body Weight]/Adult Inhalation Rate: RfC = [100 μg /kg-day x 70 kg]/20 m^3/day = 350 μg/m^3.

#http://cfpub.epa.gov/ncea/iris/index.cfm

References for Table 6

NYS (New York State). 2006. New York State Brownfield Cleanup Program, Development of Soil Cleanup Objectives. Technical Support Document. Albany, NY: New York State Department of Environmental Conservation and New York State Department of Health.

WHO (World Health Organization). 2003. Safety Evaluation of Certain Food Additives / prepared by the Fifty-Ninth Meeting of the Joint FAO/WHO Expert Committee on Food Additives (JECFA). WHO Food Additives Series: 50. Geneva, SZ: International Programme on Chemical Safety. [Last accessed on 12 01 08 on-line at http://www.inchem.org/documents/jecfa/jecmono/v50je01.htm]

Table 8.7 Thomas Jefferson Field – Ratio of Measured Concentration/Reference Concentration (Hazard Quotient) for Chemicals Selected for Health Risk Evaluation (see Table 8.4 for Measured Air Concentrations)

Name	Hazard Quotient (rounded to one significant figure)*									
	Type of Toxicity Value	Upwind of field @ 3 ft above surface	On-field in shade @ surface	On-field in shade @ 3 ft above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 ft above surface	Center of field in the sun @ 6 ft above surface	Downwind of field @ surface	Downwind of field @ 3 ft above surface	Downwind of field @ 6 ft above surface
Chemicals Detected in Field Survey Also Detected in DEC Laboratory Off-gassing Study										
1,4-Dichlorobenzene	chemical-specific	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001	0.0002	0.0001
4-Methyl-2-pentanone	chemical-specific	ND	ND	ND	0.0004	ND	ND	ND	ND	ND
Benzene	chemical-specific	0.01	0.01	0.02	ND	0.02	0.02	0.01	0.01	0.009
Benzene, 1-ethyl-4-methyl-	surrogate-chemical: xylenes (dimethyl benzenes)	0.004**	0.007**	0.005**	-	0.005**	0.004**	0.004**	0.006**	0.003**
Nonane	surrogate-chemical: hexane	0.002**	0.002**	0.001**	0.001**	0.001**	0.004**	0.001**	0.001**	0.003**
Chemicals on Target List Detected in Field Survey Not Included in DEC Off-gassing Study										
Freon 11	surrogate-chemical: HCFC 22	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Freon 113	chemical-specific	< 0.0001	ND	< 0.0001	< 0.0001	ND	< 0.0001	< 0.0001	< 0.0001	ND
Methylene Chloride	chemical-specific	0.0003	ND	0.0004	0.0004	0.0003	0.0004	0.0007	0.0002	0.0002
Chemicals Detected in Field Survey Reported as Non-Detects in DEC Laboratory Off-gassing Study										
Chloroform	chemical-specific	ND	0.002	0.003	ND	ND	0.003	ND	0.002	ND
Chemicals Detected in Field Survey as TICs										
1,3-Pentadiene	surrogate-chemical: 1,3-butadiene	0.2**	0.3**	-	-	-	0.6**	0.3**	0.3**	-
1,3-Pentadiene, (E)-	surrogate-chemical: 1,3-butadiene	-	-	-	-	-	-	-	0.3**	-

Name	Hazard Quotient (rounded to one significant figure)*									
	Type of Toxicity Value	Upwind of field @ 3 ft above surface	On-field in shade @ surface	On-field in shade @ 3 ft above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 ft above surface	Center of field in the sun @ 6 ft above surface	Downwind of field @ surface	Downwind of field @ 3 ft above surface	Downwind of field @ 6 ft above surface
1,4-Pentadiene	surrogate-chemical: 1,3-butadiene	-	-	-	-	-	-	-	-	0.3**
Butane, 2-methyl-	surrogate-chemical: hexane	–	-	0.0007**	0.0005**	-	-	0.0005**	0.0004***	0.0004**
Decanal	surrogate-chemical: propanal (propionaldehyde)	-	-	-	0.06**	-	-	-	-	-
Heptane	surrogate-chemical: hexane	0.0004**	0.0006**	-	0.0005**	-	-	-	0.0004**	-

*ND = not detected; - = not reported.

**** Based on estimated chemical concentration and tentative chemical identification.**

Table 8.8 Thomas Jefferson Field – Estimated Excess Cancer Risks from Continuous Lifetime Exposure at Measured Air Concentrations of Known or Potential Cancer-Causing Chemicals Selected for Health Risk Evaluation (see Table 8.4 for Measured Air Concentrations)

Name	Excess Lifetime Risk (rounded to one significant figure)*									
	Type of Toxicity Value	Upwind of field @ 3 ft above surface	On-field in shade @ surface	On-field in shade @ 3 ft above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 ft above surface	Center of field in the sun @ 6 ft above surface	Downwind of field @ surface	Downwind of field @ 3 ft above surface	Downwind of field @ 6 ft above surface
Chemicals Detected in Field Survey Also Detected in DEC Laboratory Off-gassing Study										
1,4-Dichlorobenzene	chemical-specific	0.4×10^{-6}	0.6×10^{-6}	0.4×10^{-6}	0.5×10^{-6}	0.4×10^{-6}	0.4×10^{-6}	0.3×10^{-6}	0.4×10^{-6}	0.3×10^{-6}
Benzene	chemical-specific	3×10^{-6}	3×10^{-6}	3×10^{-6}	ND	4×10^{-6}	4×10^{-6}	3×10^{-6}	3×10^{-6}	2×10^{-6}
Chemicals on Target List Detected in Field Survey Not Included in DEC Off-gassing Study										
Methylene Chloride	chemical-specific	0.004×10^{-6}	ND	0.006×10^{-6}	0.006×10^{-6}	0.005×10^{-6}	0.006×10^{-6}	0.01×10^{-6}	0.004×10^{-6}	0.004×10^{-6}
Chemicals Detected in Field Survey Reported as Non-Detects in DEC Laboratory Off-gassing Study										
Chloroform	chemical-specific	ND	0.007×10^{-6}	0.01×10^{-6}	ND	ND	0.009×10^{-6}	ND	0.006×10^{-6}	ND
Chemicals Detected in Field Study as TICs										
1,3-Pentadiene	surrogate-chemical: 1,3-butadiene	2×10^{-5}**	2×10^{-5}**	-	-	-	4×10^{-5}**	2×10^{-5}**	2×10^{-5}**	-
1,3-Pentadiene, (E)-	surrogate-chemical: 1,3-butadiene	-	-	-	-	-	-	-	2×10^{-5}**	-
1,4-Pentadiene	surrogate-chemical 1,3-butadiene	-	-	-	-	-	-	-	-	2×10^{-5}**

** ND = not detected; - = not reported.

** Based on estimated chemical concentration and tentative chemical identification.

Table 8.9 John Mullaly Field – Ratio of Measured Concentration/Reference Concentration (Hazard Quotient) for Chemicals Selected for Health Risk Evaluation (see Table 5 for Measured Air Concentrations)

Name	Type of Toxicity Value	Hazard Quotient (rounded to one significant figure)*								
		Upwind of field @ 3 ft above surface	On-field in shade @ surface	On-field in shade @ 3 ft above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 ft above surface	Center of field in the sun @ 6 ft above surface	Downwind of field @ surface	Downwind of field @ 3 ft above surface	Downwind of field @ 6 ft above surface
Chemicals Detected in Field Survey Also Detected in DEC Laboratory Off-gassing Study										
4-Methyl-2-pentanone	chemical-specific	ND	0.0003	ND	0.0002	ND	ND	ND	ND	ND
Acetone	chemical-specific	ND	0.00002	0.00002	ND	0.00002	0.00002	ND	ND	ND
Benzothiazole	default value	ND	ND	ND	0.4	ND	ND	ND	ND	ND
Chemicals on Target List Detected in Field Survey Not Included in DEC Off-gassing Study										
Freon 11	surrogate-chemical: HCFC 22	< 0.00001	0.00001	0.00001	< 0.00001	< 0.00001	< 0.00001	0.00001	< 0.00001	0.00001
Freon 113	chemical-specific	< 0.00001	< 0.00001	< 0.00001	ND	ND	ND	< 0.00001	< 0.00001	< 0.00001
Freon 12	surrogate-chemical: HCFC 22	0.00001	0.00002	0.00002	< 0.00001	< 0.00001	< 0.00001	0.00002	0.00002	0.00002
Methylene Chloride	chemical-specific	0.0005	0.006	0.002	0.002	ND	0.0003	0.008	0.0009	0.0004
Chemicals Detected in Field Survey Reported as Non-Detects in DEC Laboratory Off-gassing Study										
Chloroform	chemical-specific	ND	0.002	0.002	ND	ND	ND	0.003	0.002	0.002
Chloromethane	chemical-specific	ND	0.001	ND	ND	ND	ND	0.001	ND	0.001
Chemicals Detected in Field Survey as TICs										
1,3-Butadiene, 2-methyl-	surrogate-chemical: 1,3-butadiene	-	-	-	-	-	0.1**	-	-	-

Name	Type of Toxicity Value	Hazard Quotient (rounded to one significant figure)*								
		Upwind of field @ 3 ft above surface	On-field in shade @ surface	On-field in shade @ 3 ft above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 ft above surface	Center of field in the sun @ 6 ft above surface	Downwind of field @ surface	Downwind of field @ 3 ft above surface	Downwind of field @ 6 ft above surface
1,3-Pentadiene	surrogate-chemical: 1,3-butadiene	-	0.3**	0.3**	-	-	-	0.3**	0.2**	0.2**
Benzaldehyde, ethyl-	surrogate-chemical: benzaldehyde	-	0.03**	-	-	-	-	-	-	-
Cyclohexane, 1,1,3-trimethyl-	surrogate-chemical: cyclohexane	-	-	0.0001**	-	-	-	-	-	-
Cyclohexane, 1,4-dimethyl-	surrogate-chemical: cyclohexane	-	-	0.0002**	-	-	-	-	-	-
Pentane	surrogate-chemical: hexane	-	0.0007**	0.0006**	-	-	-	-	-	-
Pentane, 2-methyl-	surrogate-chemical: hexane	-	-	-	-	-	-	0.0005**	0.0004**	0.0005**

*ND = not detected; - = not reported.

** Based on estimated chemical concentration and tentative chemical identification.

Table 8.10 John Mullaly Field – Estimated Excess Cancer Risks from Continuous Lifetime Exposure at Measured Air Concentrations of Known or Potential Cancer-Causing Chemicals Selected for Health Risk Evaluation (see Table 5 for Measured Air Concentrations)

Name	Type of Toxicity Value	Excess Lifetime Risk (rounded to one significant figure)*								
		Upwind of field @ 3 ft above surface	On-field in shade @ surface	On-field in shade @ 3 ft above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 ft above surface	Center of field in the sun @ 6 ft above surface	Downwind of field @ surface	Downwind of field @ 3 ft above surface	Downwind of field @ 6 ft above surface
Chemicals on Target List Detected in Field Survey Not Included in DEC Off-gassing Study										
Methylene Chloride	chemical-specific	0.007×10^{-6}	0.08×10^{-6}	0.03×10^{-6}	0.04×10^{-6}	ND	0.004×10^{-6}	0.1×10^{-6}	0.01×10^{-6}	0.006×10^{-6}
Chemicals Detected in Field Survey Reported as Non-Detects in DEC Laboratory Off-gassing Study										
Chloroform	chemical-specific	ND	0.006×10^{-6}	0.006×10^{-6}	ND	ND	ND	0.01×10^{-6}	0.006×10^{-6}	0.006×10^{-6}
Chemicals Detected in Field Survey as TICs										
1,3-Butadiene, 2-methyl-	surrogate-chemical: 1,3-butadiene	-	-	-	-	-	8×10^{-6}**	-	-	-
1,3-Pentadiene	surrogate-chemical: 1,3-butadiene	-	2×10^{-5}**	2×10^{-5}**	-	-	-	2×10^{-5}**	2×10^{-5}**	2×10^{-5} **

* ND = not detected; - = not reported.

** Based on estimated chemical concentration and tentative chemical identification.

Table 9.1 American Academy of Pediatrics
Limitations on Activities at Different Wet Bulb Globe Temperatures

WBGT		Limitations on Activities
°C	°F	
< 24	< 75	All activities allowed, but be alert for early symptoms of heat-related illness in prolonged events
24.0–25.9	75.0–78.6	Longer rest periods in the shade; enforce drinking every 15 minutes
26–29	79–84	Stop activity of unacclimatized persons and other persons with high risk; limit activities of all others (disallow long-distance races, reduce duration of other activities)
> 29	> 85	Cancel all athletic activities

Table 9.2 Central Park Monitor - Meteorological Data

	2000 - 2007		Dates of Measurements	
	Daily Maximum Temperature (°F)	Daily Minimum Relative Humidity (%)	Daily Maximum Temperature (°F)	Daily Minimum Relative Humidity (%)
August				
Average (range)	82 (59 – 102)	53 (24 – 90)	83 (73 – 87)	42 (34 – 60)
50th prctl	82	50		
90th prctl	92	76		
September				
Average (range)	75 (54 – 91)	53 (26 – 97)	75 (69 – 83)	45 (38 – 57)
50th prctl	76	51		
90th prctl	83	76		

Table 9.3 Thomas Jefferson Field
Comparison Between Synthetic Turf and Other Surfaces

Difference (°F)	Minimum	Mean	Maximum	Standard Deviation
Turf - grass	13	42	78	19
Turf - sand	8	40	63	19

Table 9.4 John Mullaly Field
Comparison Between Synthetic Turf and Other Surfaces

Difference (°F)	Minimum	Mean	Maximum	Standard Deviation
Turf - grass	8	35	63	17
Turf - sand	8	26	50	14

Figures

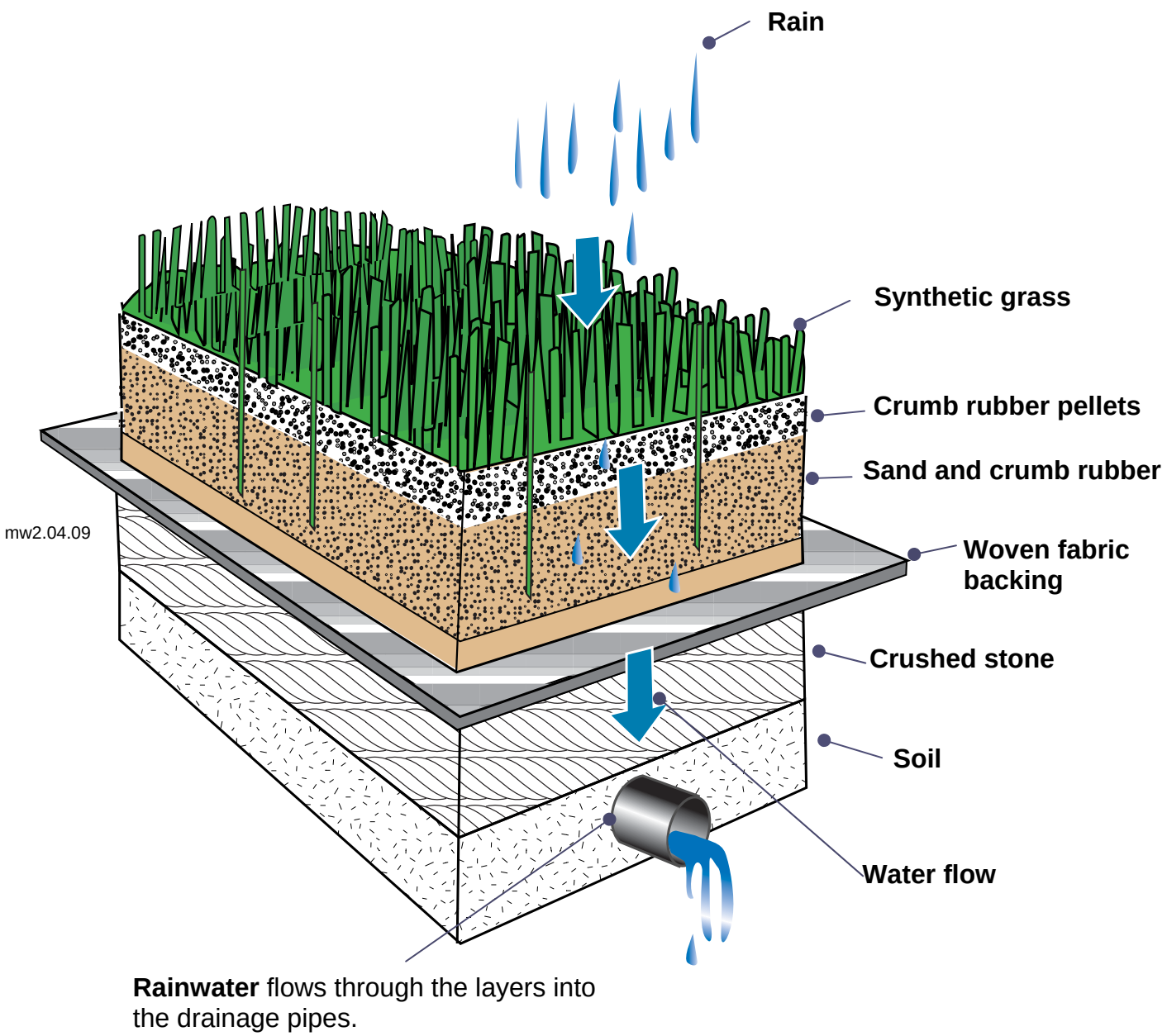


Figure 1.1 Cross-section of a typical synthetic turf field configuration

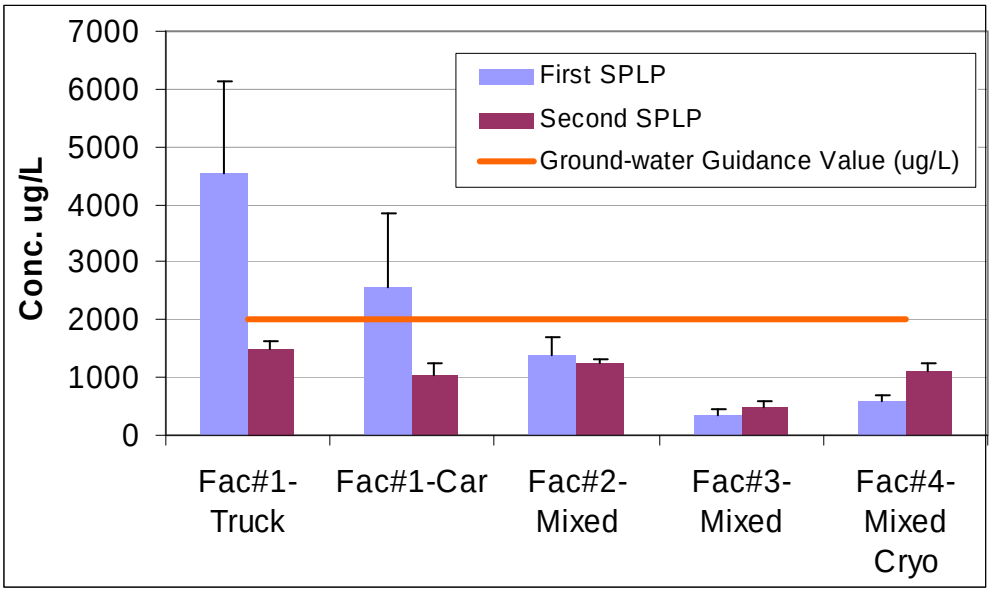


Figure 2.1 Zinc concentration in SPLP tests

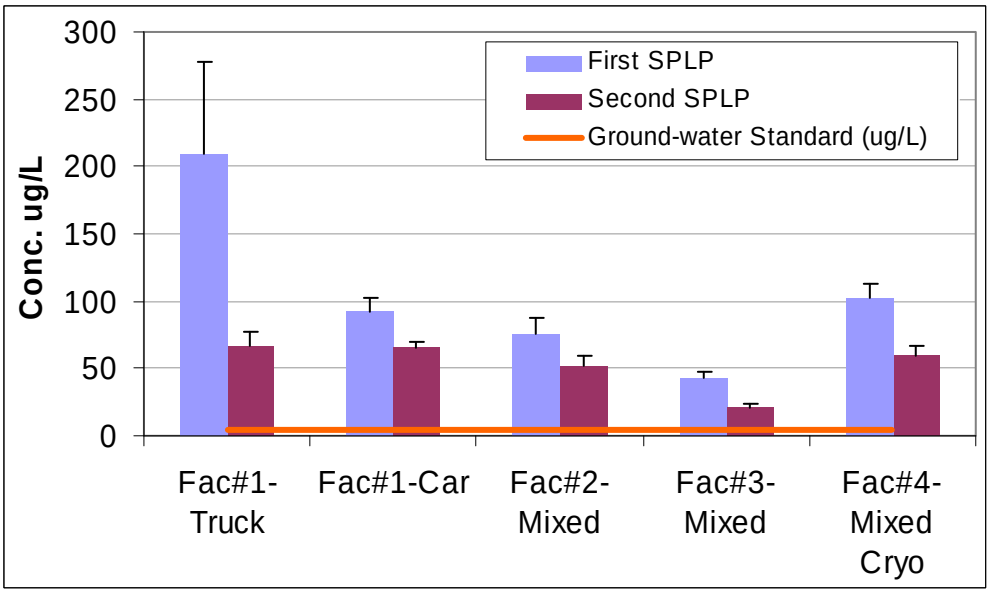


Figure 2.2 Aniline concentration in SPLP leachate

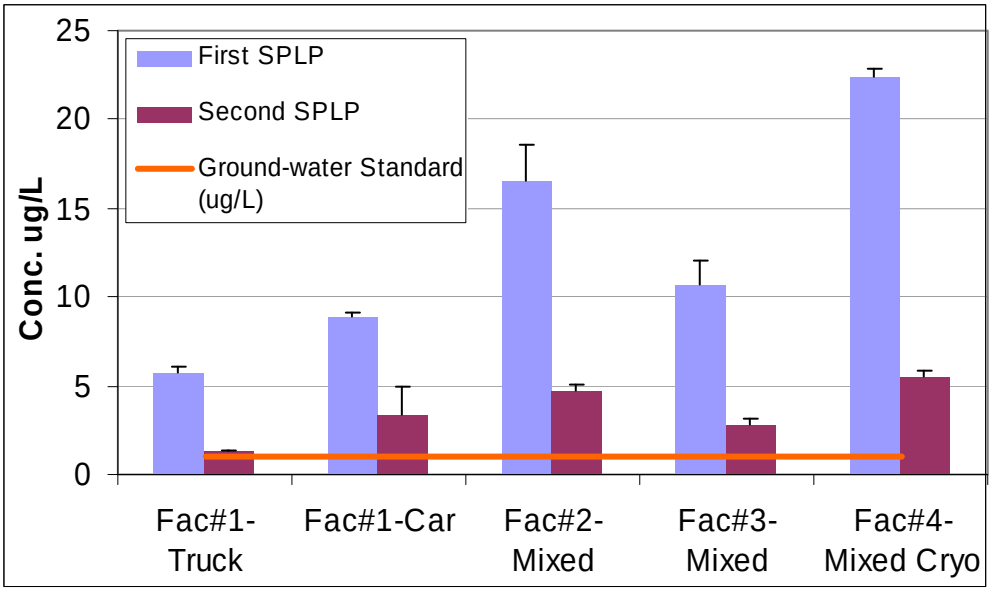


Figure 2.3 Phenol concentration in SPLP leachate

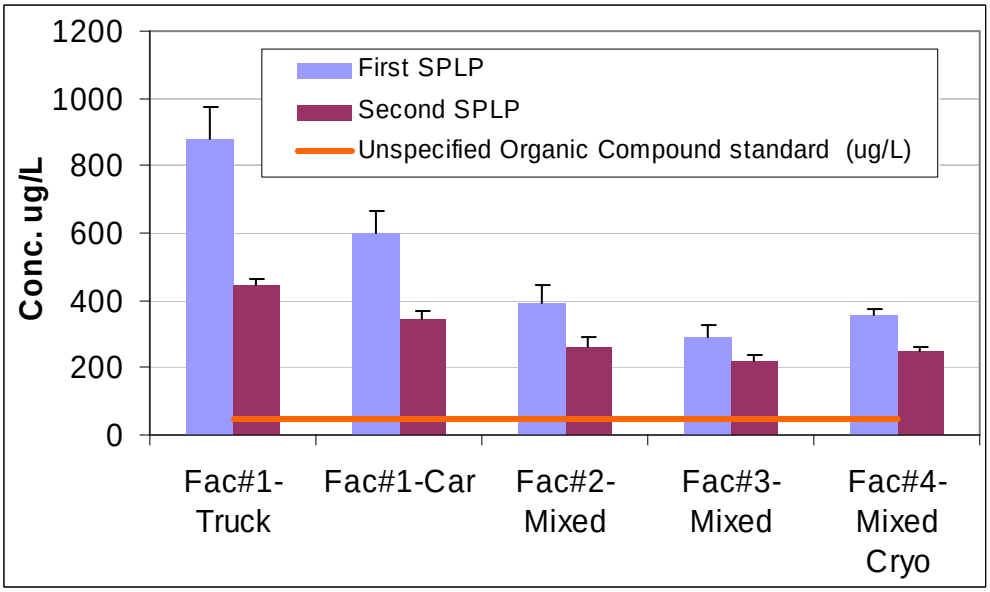


Figure 2.4 Benzothiazole in SPLP leachate

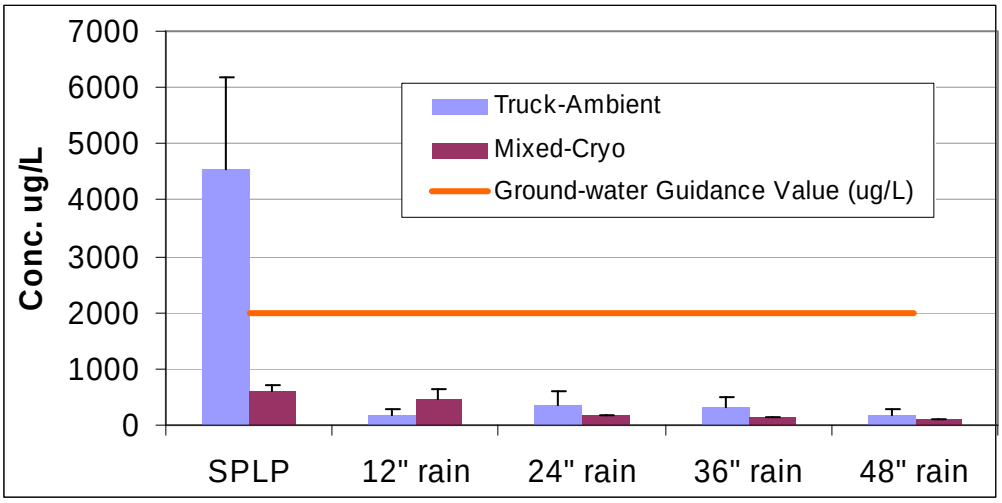


Figure 3.1 Comparison of zinc levels between SPLP and column tests

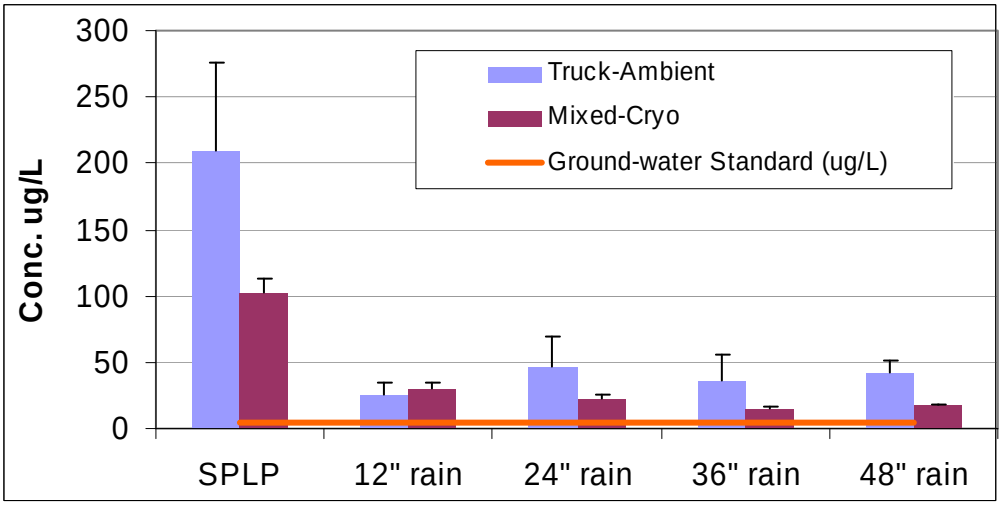


Figure 3.2 Comparison of aniline levels between SPLP and column tests

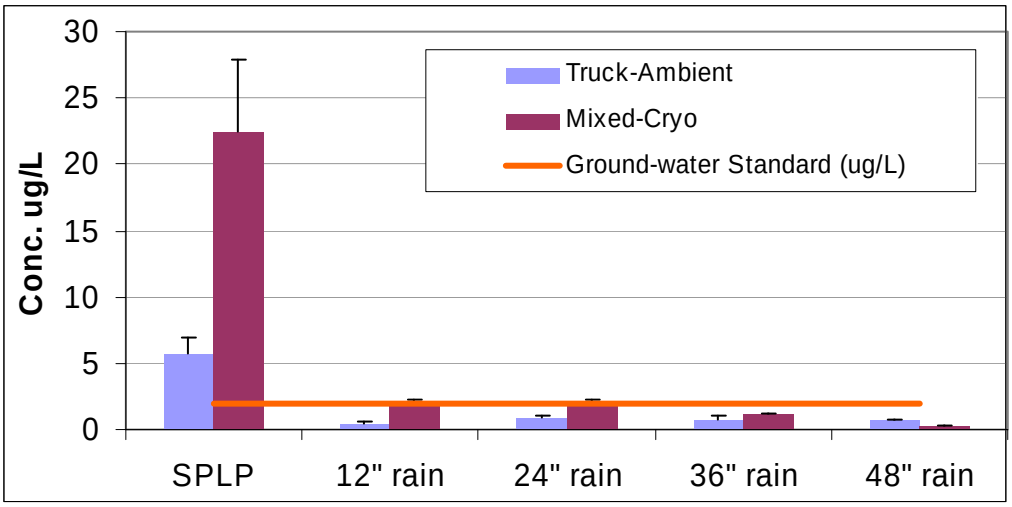


Figure 3.3 Comparison of phenol levels between SPLP and column tests

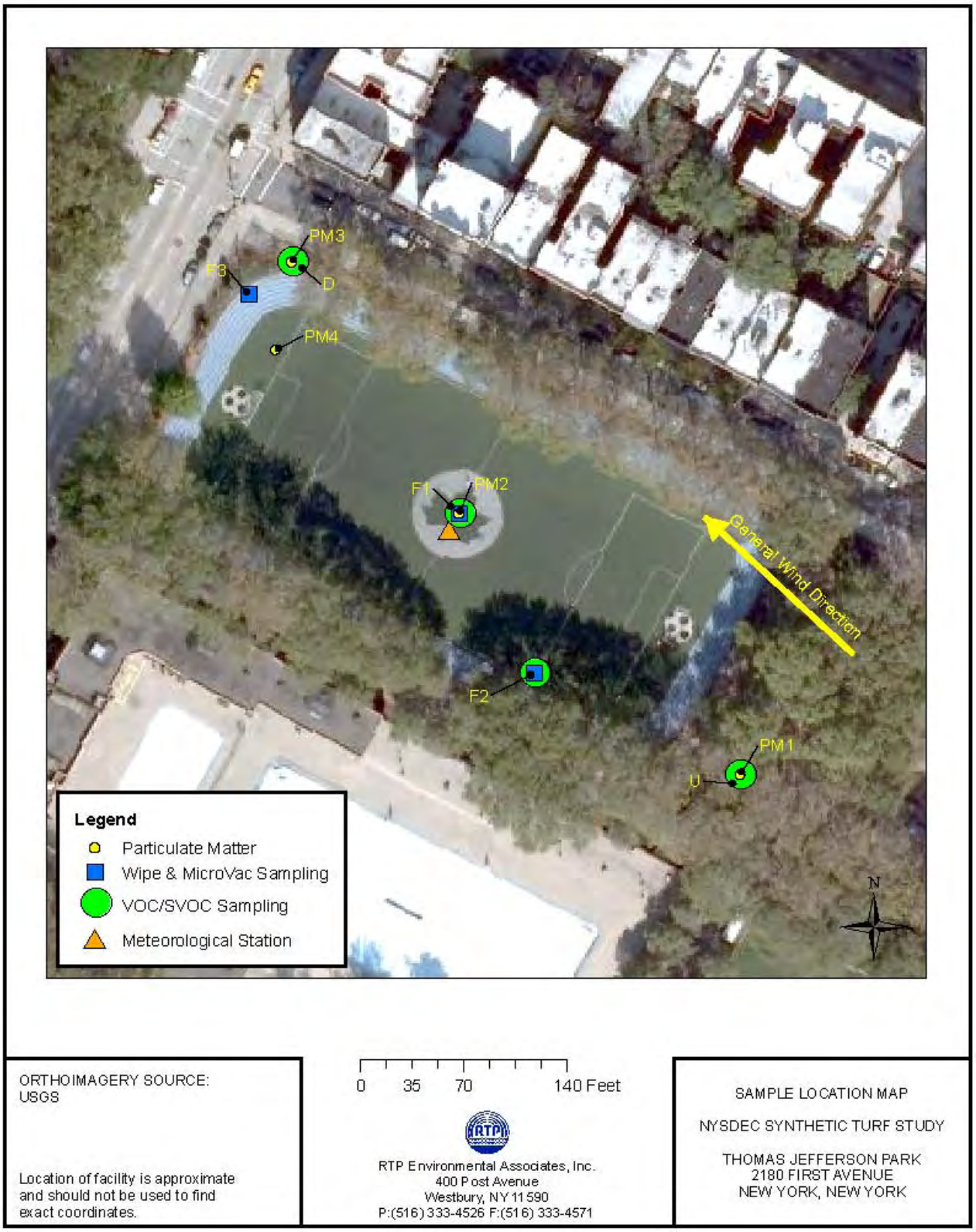


Figure 7.1 Thomas Jefferson Park Sampling Locations

ORTHOIMAGERY SOURCE:
USGS

Location of facility is approximate and should not be used to find exact coordinates.

0 35 70 140 Feet

RTP Environmental Associates, Inc.
400 Post Avenue
Westbury, NY 11590
P:(516) 333-4526 F:(516) 333-4571

SAMPLE LOCATION MAP

NYSDEC SYNTHETIC TURF STUDY

JOHN MULLALY PARK
40 EAST 164th STREET
BRONX, NEW YORK

Figure 7.2 John Mullaly Park Sampling Locations

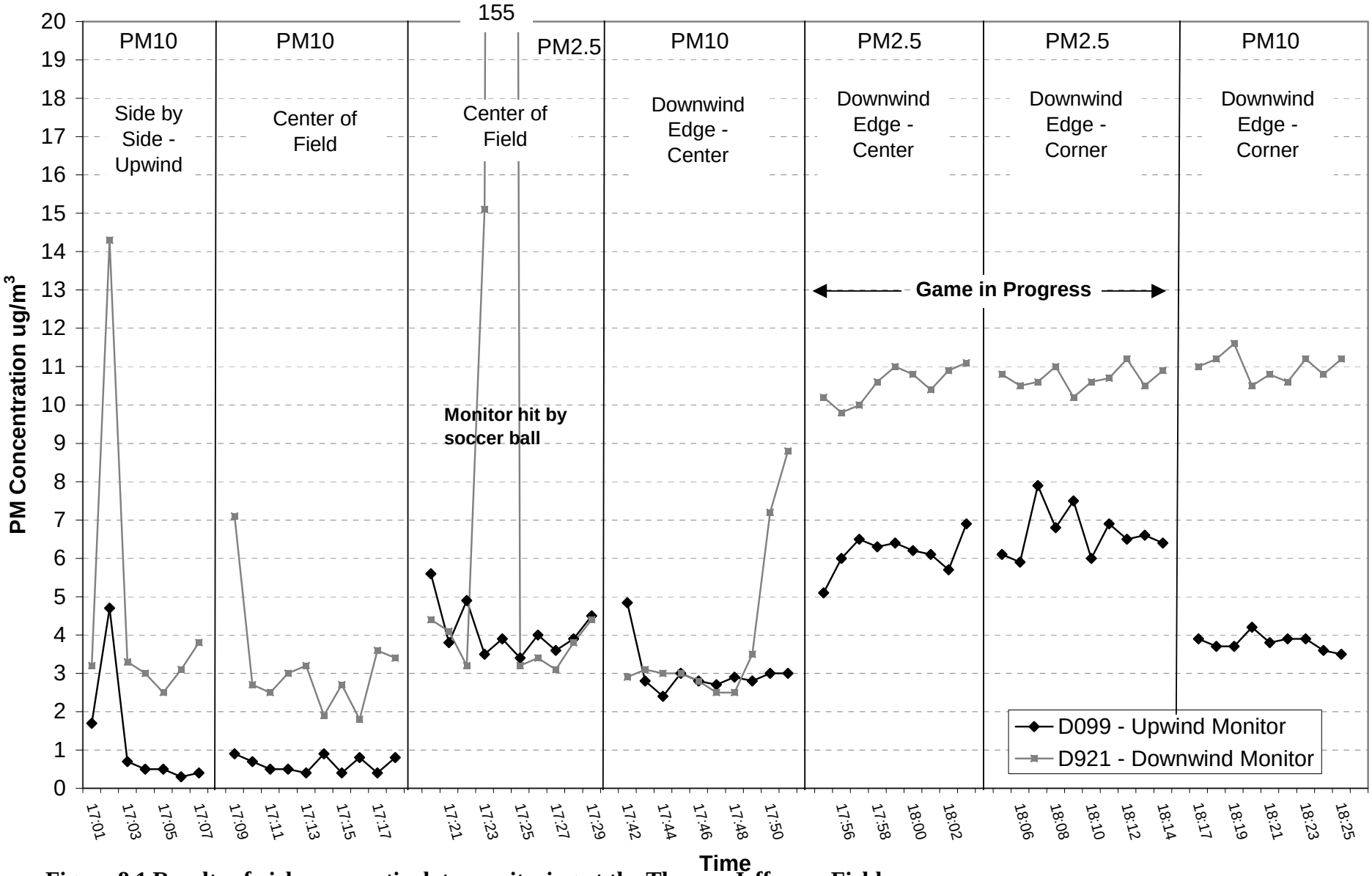


Figure 8.1 Results of airborne particulate monitoring at the Thomas Jefferson Field

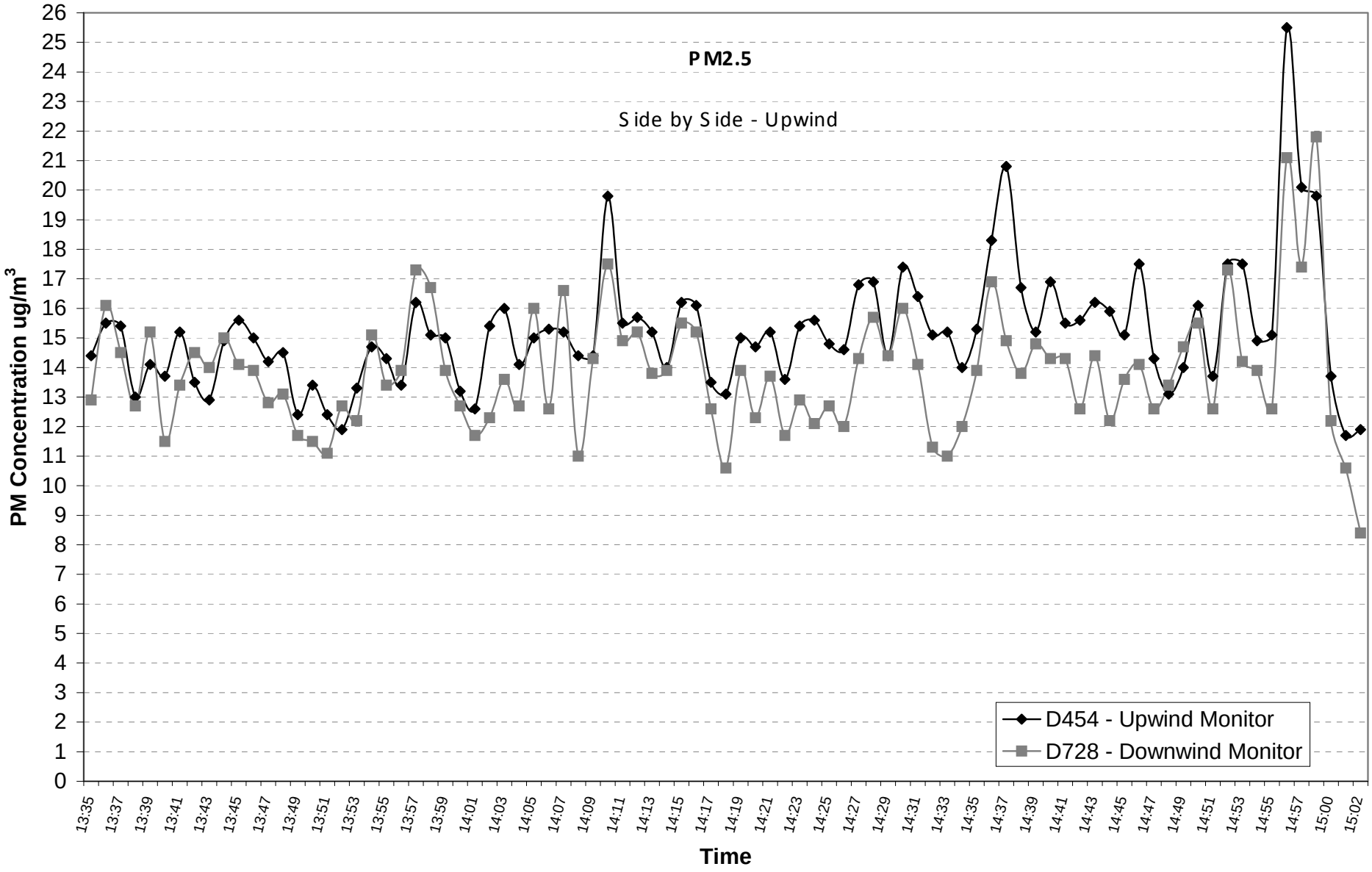


Figure 8.2 Results of side by side monitoring for airborne particulate monitoring at the upwind location on the John Mullaly Field

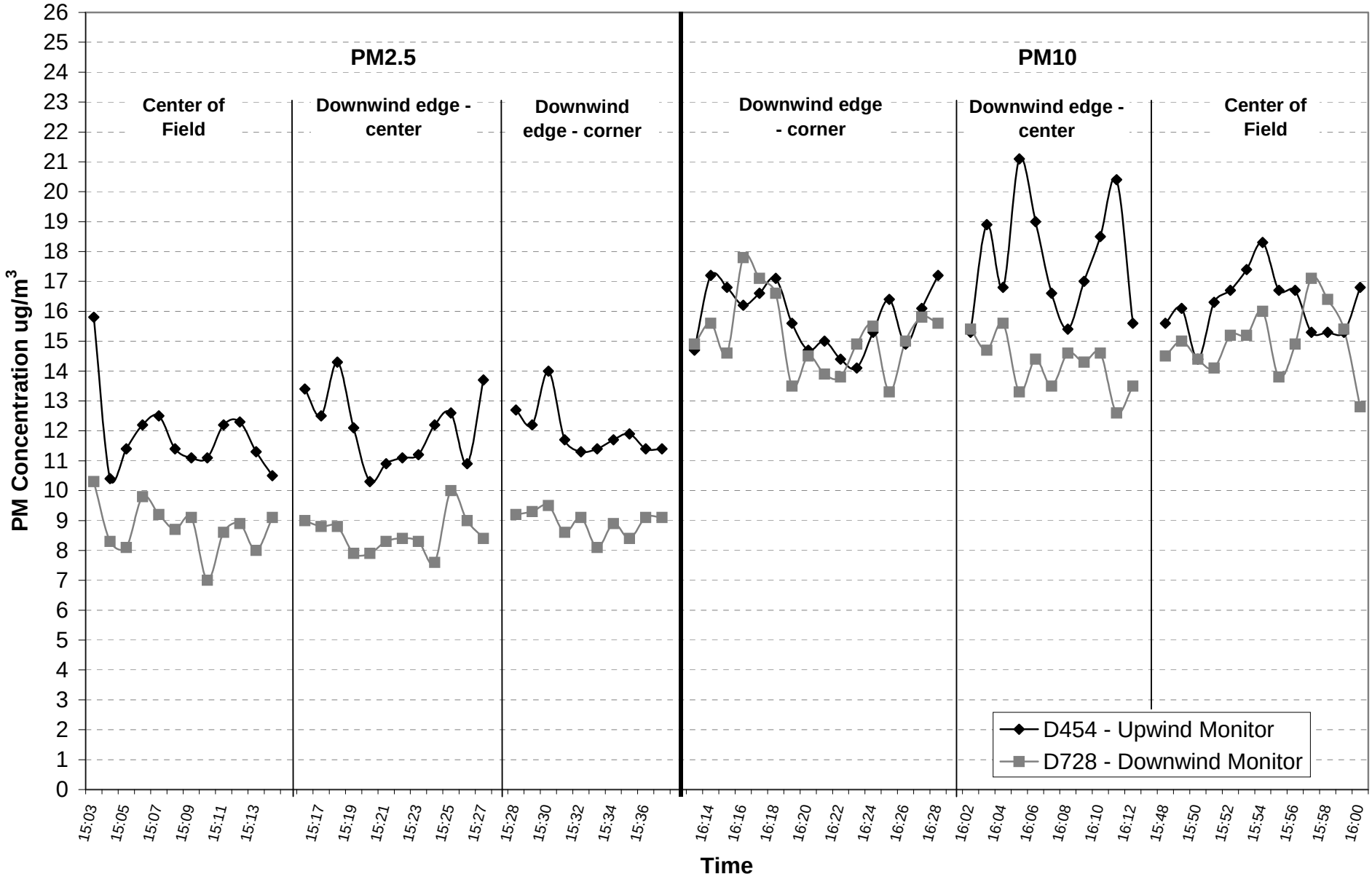


Figure 8.3 Results of airborne particulate monitoring at the John Mullaly Field

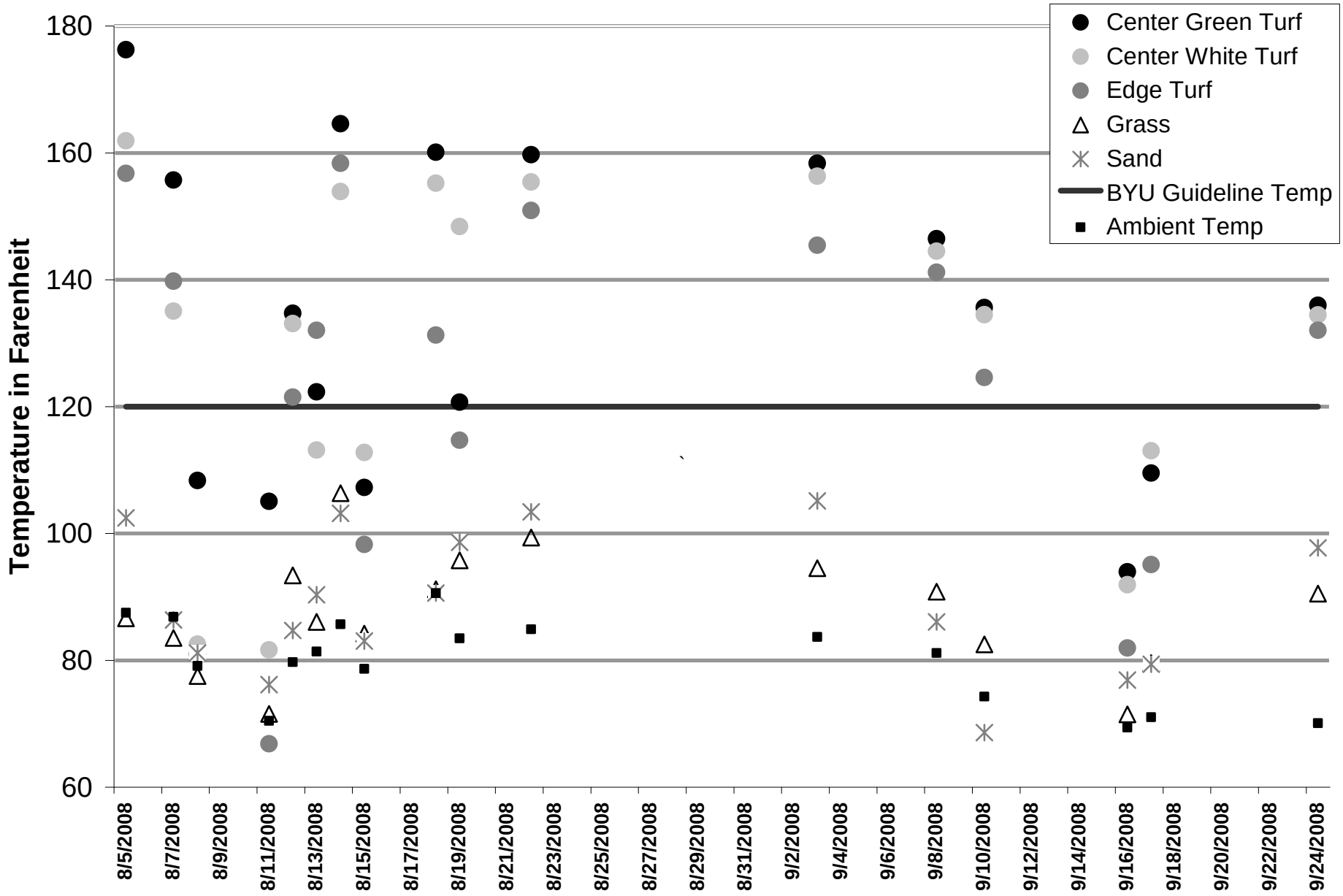


Figure 9.1 Thomas Jefferson field surface temperature measurements by date

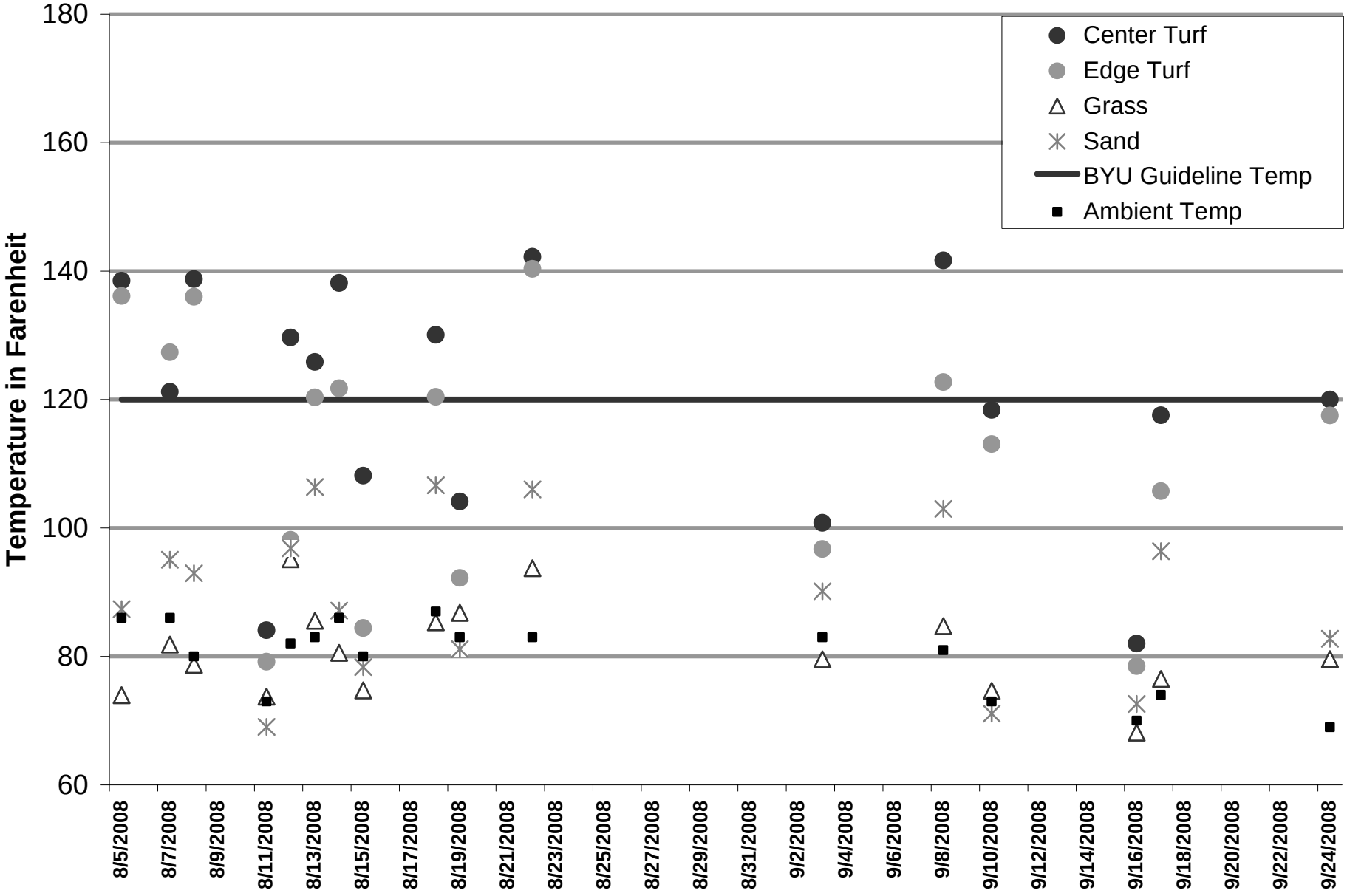


Figure 9.2 John Mullaly field surface temperature measurements by date

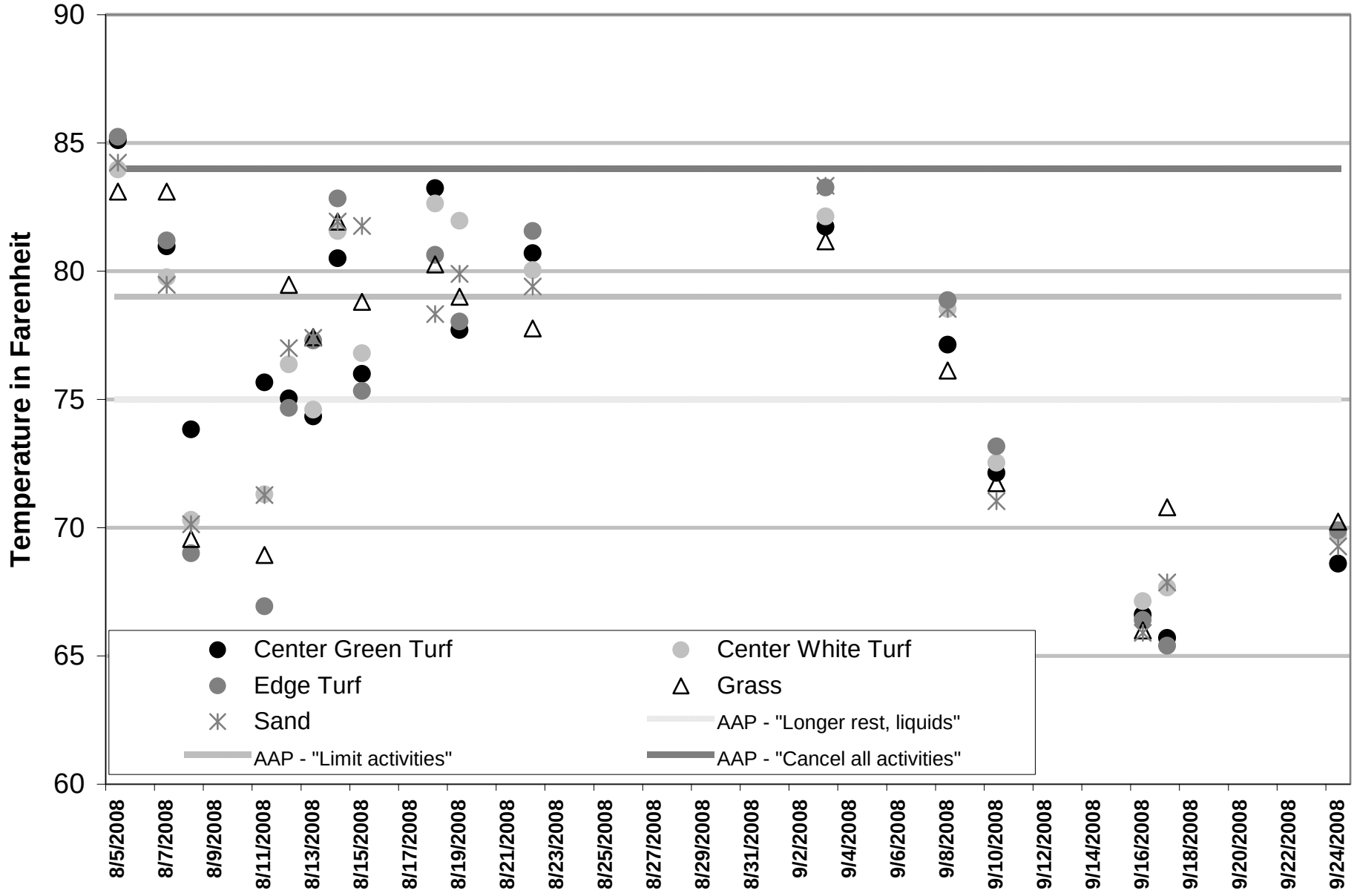


Figure 9.3 Thomas Jefferson field wet bulb globe temperatures by date

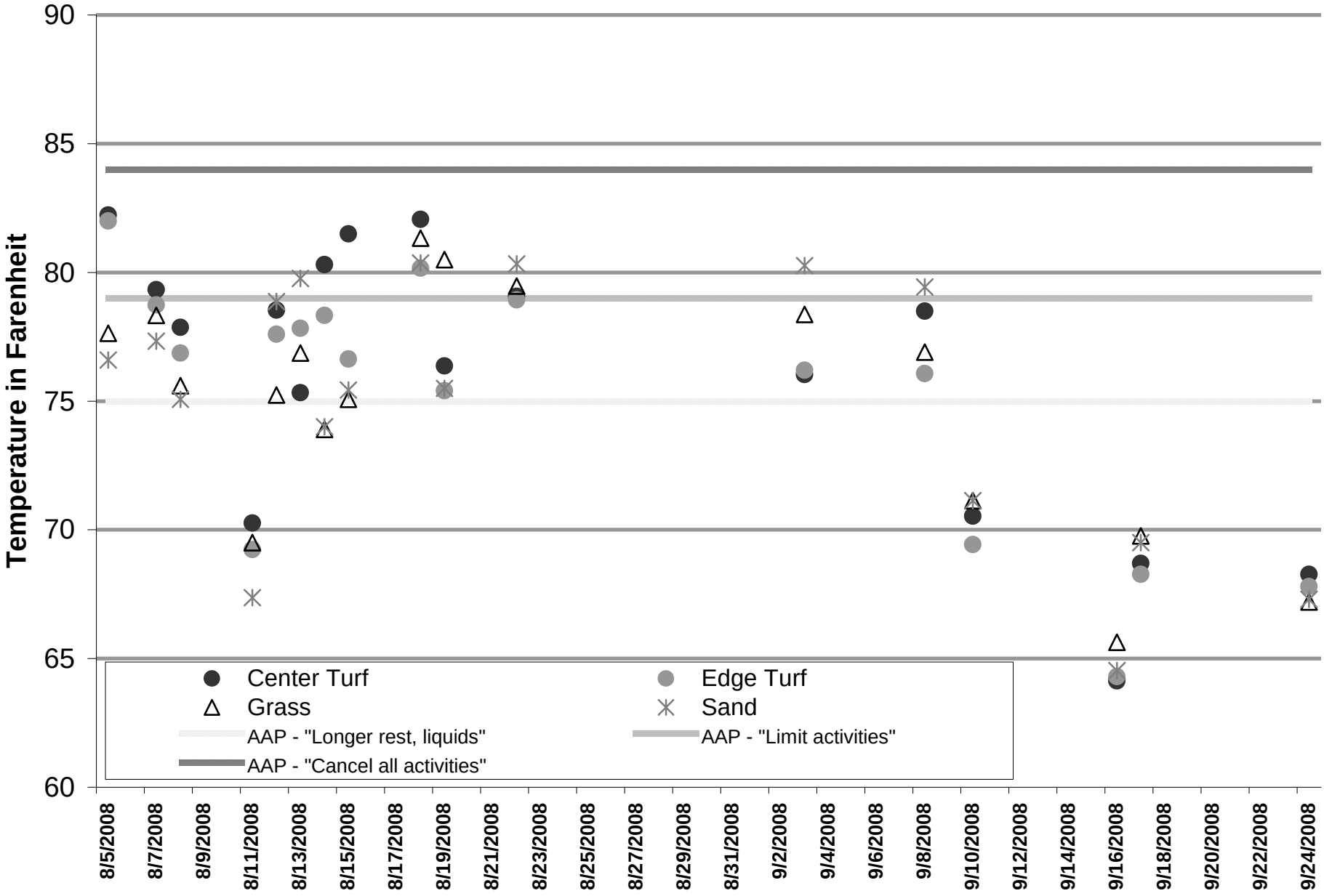


Figure 9.4 John Mullaly field wet bulb globe temperatures by date

RIDGEWOOD ENVIRONMENTAL ADVISORY COMMITTEE

REAC

Assessment of Environmental, Health and Human Safety Concerns Related to the Synthetic Turf Surface at Maple Park in Ridgewood, NJ

January - October 2009

INTRODUCTION

The Ridgewood Environmental Advisory Committee (REAC) is an independent volunteer committee, appointed by the Village Council, with experience and/or interest in environmental issues. REAC advises the Village Council on environmental, health and human safety issues in Ridgewood. It also seeks to assist the residents of Ridgewood in addressing environmental concerns by advocating "best practices", which protect the environment, respect the ecosystem and promote sustainability.

In November 2006, Ridgewood replaced a grass field at Maple Park with a synthetic field manufactured by FieldTurf. Media reports of concerns over synthetic turf fields in NJ received national attention in 2008, prompting REAC to form a sub-committee to conduct a 10-month assessment of whether these concerns affect the residents of Ridgewood. REAC focused on identifying the most current and objective information on synthetic turf, in order to provide an unbiased reference resource for the residents of the Village of Ridgewood.

Some publicized concerns were based on obsolete information and field designs, which are not relevant at Maple Park. Climates that differ significantly from Ridgewood's and dense urban environments may pose concerns that do not exist in Ridgewood. Therefore, **REAC's assessment focused <u>only</u> on concerns, which may be applicable in Ridgewood and are specific to the synthetic "infill" turf field design at Maple Park.** When direct test results were not possible, the most current and relevant data from authoritative and credible sources was considered. Where conflicting data exists, REAC adhered to a priority protocol to draw conclusions, as follows; **1)** Actual test results or experiences in Ridgewood, **2)** Outside testing with methodology that closely replicates "real life" conditions in Ridgewood, **3)** Data provided by governing or regulatory agencies (Department of Environmental Protection, etc.) **4)** Other relevant testing and "expert" commentary, believed to be credible.

The scope of REAC's assessment was limited to environmental, health and human safety issues. Financial justifications were not considered. Natural grass and current generation synthetic fields both offer environmental benefits and drawbacks, which may or may not be evident locally. This assessment does not endorse one surface over another. The objective was to present an understanding of the facts regarding specific environmental and safety issues, in a clear and concise format for reference by Village residents. REAC's conclusions are summarized on the following pages, with references and links to more detailed supporting data, upon which the conclusions are based. REAC recognizes that technology and future research may offer new information. As new information becomes available, REAC intends to update this assessment.

REAC identified a number of commonly raised concerns (listed on page 4) and gathered information from the following sources:

American Journal of Sports Medicine
British Journal of Sports Medicine
California Environmental Protection Agency
Clean Washington Center (CWC)
Direct testing
Extensive review of publicly available information and independent testing
FieldTurf [1]
NBC News
NJ Dept. of Environmental Protection
NYS Dept. of Environmental Conservation
NYS Dept. of Health
Penn State University Center for Sports Surface Research
RHS Athletic Dept.
RHS Director of Health & Wellness
Ridgewood Dept. of Parks & Recreation
Ridgewood Parks & Recreation Master Plan - Comprehensive Draft dated June 23, 2008
SportTurf Managers Association
U.S. Environmental Protection Agency
The Weather Channel

1) FieldTurf provided information about their product design, manufacture, applications and specific installations. It also provided information regarding independent testing, which was not funded by FieldTurf.

CONCERNS

1) **Does the field surface at Maple Park pose a dangerous risk of exposure to lead or other harmful materials for residents or the environment?** ***(pg. 5)***

2) **Does surface heat at Maple Park pose a health or environmental concern?** ***(pg. 7)***

3) **Does the surface at Maple Park offer environmental benefits?** ***(pg. 10)***

4) **Does drainage on the field surface at Maple Park result in leaching of carcinogenic PAHs, lead or zinc into water table over time?** ***(pg. 12)***

5) **Can MRSA infections be caused by the surface at Maple Park?** ***(pg. 14)***

6) **"Field Surface Related Injuries"…RHS Experience on Maple Park vs. Grass** ***(pg. 15)***

7) **Maple Park's "Lifespan Expectations & Recyclability"** ***(pg. 17)***

8) **Does the surface at Maple Park harm the environment by eliminating the normal CO^2 absorption of natural grass?** ***(pg. 19)***

9) **Is the field design at Maple Park suitable in the flood plain?** ***(pg. 21)***

1) Does the field surface at Maple Park pose a dangerous risk of exposure to lead or other harmful materials for residents or the environment?

No. Lead chromate was previously encapsulated in the polyethylene fibers to provide UV resistance, primarily with yellow and red surface colors. The field at Maple Park was designed to use non-toxic, water-soluble paint, not permanent colored lines. The exception is the maroon "R" at center field. Because the lead chromate is encapsulated in the fibers, it is presumed not to be bioavailable (is not released through contact) and cannot be absorbed by humans or other living systems. Research shows that contact with, or incidental ingestion of, the fibers or rubber infill poses no health risk.

If a child eats a loose fiber, it will typically pass through the digestive system without risk. Some critics have raised concern if the fiber remained in the child's stomach for an extended period and digestive acids were able to break down the fiber and release the lead chromate. It is physically impossible for a child to risk exceeding the safe U.S. federal lead levels through ingestion of the fibers at Maple Park. To put this in perspective, if the fibers were bioavailable, a 50 pound child would have to ingest over 23 pounds of loose fiber, or almost 50% the child's total body weight, in a single 24-hour period to reach a level that might exceed federal safety levels. The average adult stomach can hold approximately 0.5 pounds. So, the unsafe amount of fiber is 46 times greater than can be physically contained in an average adult stomach. In addition, large amounts of fibers are not easily removed from the field surface. According to experts in New York City on May 5,2008, "it is absurdly unrealistic" to believe a child could ingest a dangerous amount of loose turf fiber.

On June 14, 2008, independent lead testing was conducted at Maple Park. Test samples were evaluated by a NJ DEP certified laboratory, EMSL Analytical in Westmont, NJ, using digestion method 3050B and analytical method 6010B (inductively coupled plasma). The turf sample test resulted in a lead content of <1.0 mg/kg, 400 times below the NJ DEP Soil Clean-Up Criteria of 400 mg/kg. And the wipe test resulted in a lead content of 1.1 µg/wipe, almost 40 times below the HUD standard for indoor floors and carpets of 40 µg/wipe. The test report described the lead concentration in the fiber as "undetectable" and said the result from the wipe test was attributed to "normal dust in the air". Similar results would also be expected on grass surfaces. There is no reason to expect lead levels to increase at Maple Park. However, REAC believes it would be prudent for Ridgewood to conduct similar tests every 3-5 years at Maple Park and at random grass playing fields in town, as a comparative benchmark.

The cryogenically ground crumb rubber infill used at Maple Park also does not appear to pose any risk to residents or the environment. Shredded tire infill (known as “ambient” rubber) may contain higher levels of fiber and metals than what is produced during the cryogenic grinding process. For a discussion of the difference between “cryogenic” rubber and “ambient” rubber, see the links to the *Clean Washington Best Practice* and *FieldTurf Q6 Quality Control* below. None of the rubber infill at Maple Park came from landfills or “tire piles”. To date, there has never been a documented report of injury or sickness anywhere in the world as a result of inhalation, ingestion or exposure to cryogenic rubber infill at a FieldTurf installation. A study from the spring to fall of 2008 by the NY State Department of Environmental Conservation found that “analysis of crumb rubber samples digested in acid revealed that the lead concentration in crumb rubber samples was well below the federal hazard standard for lead in soil and indicated that the crumb rubber from which the samples were obtained would not be a significant source of lead exposure if used as an infill material in synthetic turf fields.”

A review of available information by the California Office of Environmental Health Hazard Assessment (OEHHA) evaluated the risk of cancer from breathing the air above a synthetic “infill” field over 70 years. The lifetime cancer risk was determined to be 1 in one million. The review stated that “lifetime cancer risks of one cancer in a population of one million are considered a negligible risk level. Many common human activities result in cancer risks that are higher than one in one million.” OEHHA states on their website that the cancer risk of breathing California air (in 2000) due to diesel particles was 540 in one million (540 times greater than the risk of breathing air over a synthetic field for 70 years).

NYC Scientific Panel Discussing "Absurdly Unrealistic" Risk of Lead Exposure - May 5, 2008
Brian Williams on NBC: Turf is Safe According to CPSC - July 30, 2008
"The Record" Reverses and Reports Turf Not Dangerous - Franklin Lakes, NJ - July 30, 2008
NY Department of Environmental Conservation Crumb Rubber Infilled Field Report - May 2009
Clean Washington Center (CWC) Best Practice - Ambient vs. Cryogenic Grinding
FieldTurf Q6 Quality Control
CA Office of Environmental Health Hazard Assessment (CA EPA) - July 2009

2) Does Surface Heat at Maple Park Pose a Health or Environmental Concern? [1]

A. Does the synthetic turf surface at Maple Park reach temperatures, which might pose an unusual health risk for athletes and spectators, particularly youth athletes? If so, should special precautions be undertaken at Maple Park?

B. Do elevated ambient air temperatures from the surface at Maple Park pose an environmental concern, when compared to the natural grass at the RHS Stadium Field?

Objective analysis of synthetic fields notes elevated surface temperatures compared to natural grass. The industry recognizes the potential for elevated surface temperature. In some climates, measures may be required to cool the surface or the design's merits may need to be weighed against this issue. As detailed in the Appendix *(page 26),* the surface temperatures at Maple Park were lower than other recreational surfaces and had little or no impact on the ambient air temperature differential with natural grass. In Ridgewood's climate, surface temperatures at Maple Park do not seem to pose an environmental issue.

During REAC's testing, Maple Park's surface was an average of 30ºF hotter than the natural grass surface at the RHS Stadium Field. However, the ambient air above both surfaces differed by only 3ºF at 12" above the surface and approximately 2ºF at 39" (the approximate chest height of a typical youth athlete). The differences in the ambient air were undetectable without a thermometer. In both cases, the ambient air temperature above the surfaces was slightly higher than the general air temperature.

The surface temperatures at the RHS Tennis Courts and the RHS Track were significantly higher than that of the surface at Maple Park. The ambient air temperature above both surfaces was also generally higher. Neither of these surfaces has been identified as a potential risk to human health or the environment. REAC also took measurements above the asphalt parking lot at Graydon/Maple Park, to approximate conditions for joggers on roadways in Ridgewood. The average surface measurements in the parking lot were lower than those at the RHS Tennis Courts or the Ridgewood Track and were comparable to Maple Park.

1) A detailed discussion of REAC's temperature measurements and findings with links to videos, documenting the measurements, can be found in the Appendix on page 26.

The facilities tested are intended to be used while wearing athletic shoes. No difference in surface temperature was detected while standing on the surface with shoes. On July 12, 2009, when the hottest surface measurements were recorded at Maple Park, there were eight children playing wiffle ball, all with bare feet. When asked about the surface heat, the children indicated no discomfort.

According to the Weather Channel, the temperature in Ridgewood has only exceeded 100ºF once in the last 100 years (1962). Wind, clouds and precipitation all have a significant impact on any surface's temperature. The hottest months of the year in Ridgewood are June through September. The average high temperature in that period is 80ºF and average record high is 99ºF. It is unrealistic to expect surface temperatures to approach those reported in hotter climates. Surface temperatures at Maple Park were well within the historically acceptable and safe levels observed at other recreational surfaces in Ridgewood and did not reach levels that appear to be abnormal or unsafe. REAC's documented temperature measurements contrast with conclusions from a study of surface and soil temperatures at Brigham Young University in 2002 and, speculation about surface heat from synthetic turf posed by Stuart Gaffin, Associate Research Scientist at Columbia University, after he noticed that two of six (high surface temperature) thermal satellite images in New York city appeared to be synthetic fields.

The measurements observed in Ridgewood suggest that the concern over surface temperature is unwarranted at Maple Park. The ambient air above the surfaces, resulting from the combination of air temperature and radiated heat (from the sun and the surface) is the primary determinant of athletes' or spectators' perception of heat. The ambient temperatures above the all surfaces were between 90ºF and 99ºF. The evaluation appears to show that differences in surface temperature, alone, have little impact on the ambient temperature. The average ambient temperatures observed at 12" and 39" above the natural grass at the RHS Stadium Field and the surface at Maple Park were similar. The average difference was 3ºF or less. The average temperature above the surface at Maple Park dropped 20.9% at a height of 12" and dropped 21.4% at a height of 39". The average temperature above the surface at the RHS Stadium Field increased 3.6% at a height of 12" and increased 5.2% at a height of 39".

REAC's observed measurements indicated no basis for health, safety or environmental heat concern between the grass and Maple Park's synthetic surface. The same precautions required to minimize heat exposure on grass fields during elevated temperatures would also apply at Maple Park. REAC recommends that athletes and spectators use common sense and adhere to the same precautions against heat exposure whether playing on grass or artificial surfaces.

Craig Mahler, RHS Girls Soccer coach, said he changed the times of his pre-season practices (in August) to 8 am and 4 pm, but he would have done that whether it was grass or turf, just to avoid the hottest parts of the day. He said, "kids know they have to drink more water when it's hot."

REAC's observations and conclusions were corroborated by a similar independent year-long study conducted in CT, by Milone & MacBroom, a nationally known environmental consulting firm.

NOTE: Please see the detailed findings of REAC's study in the Appendix (starting on page 26).

Milone & MacBroom Comprehensive Turf Study 2009

3) Does the surface at Maple Park offer environmental benefits?

In Ridgewood's case, the Village was able to eliminate thousands of pounds of fertilizer, over a million gallons of water and 54 hours of mowing. Storm water runoff at Maple Park was improved significantly. There were also a number of environmental benefits, which were not recognized locally.

According to data provided by the Department of Parks and Recreation, prior to the installation of the synthetic surface at Maple Park, the Village used over 4,000 pounds of fertilizer at Maple Park ($1,500) every year in the months from March through November. Without specific test data at the time, it cannot be known if chemicals leached into the water table (primarily in the form of Nitrogen) and eventually ended up in the Ho-Ho-Kus Brook. This is a large sources of pollution in the United Sates. The use of fertilizer and pesticides has long been a concern with the EPA in NJ, where grass has been used to control erosion on storm water detention basins. The EPA says, "methods used to maintain turf grass…applying fertilizers and pesticides and mowing frequently (as much as 10 times during the growing season)…can negate any benefits gained in water quality and cost effectiveness. Excess soluble pesticides and fertilizers can mix with storm water runoff and be carried into receiving waters. Excess chemicals can leach into underground aquifers."

The data also shows that 200 pounds of grass seed ($1,000) and over 1,060,000 gallons of water ($3,500) were also used at Maple Park annually. The concern over Ridgewood's water resources announced in October, 2009 makes this a particularly important benefit. In addition, emissions from tractors during 54 hours of mowing the grass at Maple Park (1.5 hours a week for 36 weeks) was eliminated. These benefits are a positive step for the environment in Ridgewood. Quantifying the environmental benefit is difficult. Other materials and labor costs at Maple did not necessarily have an environmental impact.

U.S. EPA Website - Sources of Nonpoint Pollution

Perhaps the most important environmental benefit at Maple Park is the improvement of the storm water runoff management in the flood plain *(this will be discussed in more detail on page 21).* According to the Department of Parks and Recreation's records, the peak storm water runoff into the Ho-Ho-Kus Brook was reduced over 95% for a "2-year storm" event and over 94% for a "10-year storm" event. In fact, today the peak runoff in a "10-year storm" event is 72% lower than it was for a "2-year storm" event with the previous non-engineered natural grass surface and water capture/drainage system.

REAC learned that there are also important environmental benefits to the field design at Maple Park that are are not felt locally. Maple Park permanently prevented approximately 40,000 tires from going to landfills and, in the future, will be recycled in other commercial applications. The manufacturer of the turf at Maple Park is recognized as a member of the U.S. Green Building Council and the Environmental Protection Agency's "Greenscapes" program for their leadership in recycling, water conservation and environmental focus. A FieldTurf installation can earn as many as ten LEED® (Leadership in Energy & Environmental Design) credits.

In several respects, the synthetic surface at Maple Park represents an environmental improvement over the previous natural grass field. An added benefit noted by youth sports groups and RHS coaches is that flocks of Canadian Geese no longer leave droppings on the field, posing a health risk to athletes and fowling the Ho-Ho-Kus Brook along the park. Because the geese can't eat the synthetic fibers, they no longer are attracted to the site and avoid it.

Potential LEED Credits for FieldTurf Installations
"LEED-ing the Way" - Athletic Facility Design (FieldTurf case study reprint)

4) Does drainage on the field surface at Maple Park result in leaching of carcinogenic PAHs, lead or zinc into water table over time?

Several recent studies explored this concern in great depth and found no basis for health or environmental concern due to leaching of hazardous materials from synthetic turf installations, similar to the one at Maple Park. The materials used at Maple Park are regulated by national building codes (similar to the carpet industry) and the installation of such fields in NJ is closely controlled through the NJ DEP permitting process. This concern arises from the idea that the crumb rubber or polyethylene fibers breakdown over time and release toxins into the water table. New FieldTurf surfaces are lead-free and virtually all heavy metals are removed from the crumb rubber during cryogenic grinding processing.

The question is, if traces of these metals remain, can they be released in levels that pose a danger? Some groups, such as Environment and Human Health, Inc. (EHHI), claim that this is the case. However, their conclusions appear to be based on extreme laboratory testing methodology that "do not replicate natural field conditions", according to D. Michael Johns, Ph.D. and Tom Goodlin, who conducted an evaluation for King County Water and Land Resource Division in Seattle. King County looked at the long term affects on water quality of synthetic turf runoff and found that the runoff had no effect on the test organisms and met all state and federal water quality standards. In the EHHI funded tests, crumb rubber was submerged in water, methanol or acid for extended periods. In some tests, the samples in the solutions were heated to as much as 300ºC (575ºF) and held at that temperature in an apparent effort to produce a desired result. EHHI rejects the findings of independent and government testing that contradicts their results, calling for more testing. In REAC's opinion, their testing methodology, calls into question the objectivity of their testing and assertions.

Johns and Goodlin noted that, "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." Tests conducted under normal environmental conditions revealed that "organic compounds generally do not seem to be released in detectable concentrations."

Studies conducted by the NY State Departments of Environmental Conservation in 2008 to assess the safety of crumb rubber in synthetic turf fields concluded that “crumb rubber may be used as an infill without significant impact on groundwater quality.” In recent independent testing, minor evidence of metals was detected. However, the levels were consistent with levels that would be found in rain water or the native soil.

In January 2009, Milone & MacBroom, a CT based firm specializing in environmental science completed their own year-long study on water quality, air quality and temperature of three synthetic fields in CT, built in 2007. Their findings were conclusive that leaching of organic compounds and heavy metals should “be of no concern with regard to the safety of synthetic fields.” The study concluded that eight water samples from three different fields “indicate that the actual storm water drainage from the fields allows for complete survival of the test species called Daphnia pulex. An analysis of the concentration of metals in the actual drainage water indicates that metals do not leach in amounts that would be considered a risk to aquatic life as compared to existing water quality standards.” Further, analysis following EPA methods “indicates that metals will leach from crumb rubber but in concentrations that are within ranges that could be expected to leach from native soil.”

REAC believes that there is sufficient evidence to support the conclusion that the field design at Maple Park poses no risk to the local environment in Ridgewood.

NY Department of Health Fact Sheet On Rubber In Filled fields
NY Department of Environmental Conservation Crumb Rubber Infilled Field Report - May 2009
Milone & MacBroom Comprehensive Turf Study 2009
King County (Seattle) Water & Land Resource Division Evaluation of Environmental Risks
Clean Washington Center (CWC) Best Practice - Ambient vs. Cryogenic Grinding
FieldTurf Q6 Quality Control

5) Can MRSA Infections Be Caused By the Surface at Maple Park?

No. MRSA infection has never been reported in connection with the synthetic surface at Maple Park or similar field designs. Several studies have proven that there is no connection between current generation synthetic surfaces and MRSA infections. The most notable among these was a study by Penn State's College of Agricultural Sciences, conducted by Andy McNitt, Associate Professor of Soil Science the University's Center for Turfgrass Science. The study tested 20 "infill" design synthetic fields at various locations in PA and found no trace of staphylococcus aureus bacterium in any of the fields. McNitt concluded that "the infill systems are not a hospitable environment for microbial activity…they tend to be dry and exposed to outdoor temperatures, which fluctuate rapidly." He went on to say that "the microbe population of natural turf grass far exceeds anything we've found in the infill systems." Personal hygiene is the most important factor in preventing the spread of MRSA, regardless of the source.

Both the Center for Disease Control and the NCAA concur that MRSA has yet to be found in synthetic turf and that McNitt's study is conclusive in its findings. This was recently supported by a review of available information conducted by the California Office of Environmental Health Hazard Assessment (OEHHA).

Penn State MRSA Study
CA Office of Environmental Health Hazard Assessment (CA EPA) - July 2009

6) "Field Surface Related Injuries"…RHS Experience on Maple Park vs. Grass

Based on discussion with the RHS coaches, RHS Director of Wellness and RHS Athletic Trainer, injuries at Maple Park are, if anything, lower than on Ridgewood's grass fields due to the poor condition of our grass fields. The critical issue, according to RHS staff, is the consistency of the playing surface. The volume of activity in Ridgewood and typical weather conditions in Ridgewood make it very difficult to maintain natural grass fields. The surface at Maple Park has allowed practices and games to occur without damaging our grass fields during inclement weather. This has helped to minimize subsequent field damage, which can contribute to field related injuries. Colder weather can make grass fields a harder surface. The surface at Maple Park does not freeze as easily and thaws quickly.

According to Mike Pounds, RHS Boys Lacrosse coach, "since the team has been playing at Maple Park (since 2007), injuries have definitely gone down, especially ankles and knees."

Craig Mahler, RHS Girls Soccer coach, said he would "rather play on grass, but that it's safer to play on a well-maintained turf field than on a poorly maintained grass field, and what we have in Ridgewood are poorly maintained grass fields." He added that a lot of information out there about turf is based on old reports dating back to the Astroturf days. The old Astroturf was "really bad…lots of twisted knees, burns, abrasions." His team often plays on Somerville's grass field, where areas have "been repeatedly re-sodded, resulting in a hump in front of the goal that led to several ACL and MCL injuries." He noted that sprinkler head areas also cause a lot of problems because the areas around the sprinkler heads are not maintained. Craig also coaches softball and said he "would prefer having dirt around the bases or even having a full dirt infield with turf elsewhere." Again the problem is maintenance, he said. "If you don't water and groom the clay, it becomes so hard that players get more injuries sliding on the dirt than sliding on artificial turf."

Although synthetic turf may be easier to maintain than natural grass, it must be maintained. During a flood in 2008, a portable soccer goal was left on Maple Park and "floated" across the field. As the goal slid along the field surface, it caused a temporary ripple in the field. The ripple was not on the playing surface and did not cause an injury. It was eventually eliminated with proper grooming. However, it emphasizes the point that synthetic fields are not indestructible and reasonable maintenance and grooming is required.

Garland Allen, RHS Director of Wellness, said “there appear to be fewer injuries (with RHS athletic teams), not so much because the artificial surface is better, but because we’ve reduced the number of practices and games on the poorly maintained grass fields in Ridgewood.”

RHS Athletic Trainer, Nick Nicolaides, said that “out of the 30 ACL tears experienced by RHS athletes in the past five years, only one occurred at Maple Field.” It should be noted that Maple Park has only had the new surface for three years.

The NYS Dept. of Health identified five studies that compared injury rates among athletes when playing on infilled synthetic turf and natural grass fields. Although the ability of the studies to detect differences in the injury rates was limited by the small number of injuries reported, the studies concluded that there were no major differences in overall injury rates between natural and infilled synthetic turf, like that at Maple Park.

An NBC News report from Dublin, OH discussed a comprehensive 5-year study done in Texas regarding the comparative safety between natural grass and turf. The study, which was published in the *American Journal of Sports Medicine* in 2004, concluded that natural grass results in a greater number of “serious” injuries, particularly concussions and knees, than the newest generation of synthetic turf. Dublin High School’s experience over a two year period supported the results in Texas. A 2-year study published in the *British Journal of Sports Medicine* in 2007 found no significant difference in the frequency or severity of injuries in men’s and women’s NCAA soccer between natural grass and the latest generation turf fields.

NBC News Report (Dublin, OH) on AJSM Article Concluding That Natural Grass Causes More Serious Injuries Than Turf
5-Year Meyers & Barnhill Texas HS Football Study 2004 - American Journal of Sports Medicine, Vol. 32, No. 7
2-Year NCAA Soccer Study 2007 - British Journal of Sports Medicine
FieldTurf Maximum Safety & Performance (MSP) Standard Video

7) Maple Park's "Lifespan Expectations & Recyclability"

The surface at Maple Park is warranted by FieldTurf for 8 years. However, the usable lifespan of the surface is expected to be 12-15 years. REAC contacted FieldTurf's corporate headquarters to understand what happens then. Darren Gill, Director of Marketing, began by explaining that "of the 3,000 fields installed by FieldTurf since 1994, only 10 have been replaced." In fact, the first installation from 1994 is still in use. The drainage system beneath the field surface is permanent. However, once the field reaches the end of its usable life, the fiber "carpet" and sand/rubber infill will be replaced.

In 1999 FieldTurf installed 60 fields. Since those fields will be approaching the end of their useful life in the next 2-5 years, FieldTurf has focused its attention on the issue of recyclability. According to Gill, "finding ways to recycle the field materials is the the #1 research and development effort at the company today." Gill emphasized that, "as part of any new contract, FieldTurf will guarantee that the field materials will be recycled when the field is replaced." He assured REAC that this applies to the field at Maple Park, as well, even though it was installed before this new policy was established.

There are four materials used in the field, which collectively have an unlimited number of recycling applications. According to Gill, the key is to identify those applications that are most economically viable and focus on those areas. In some cases, the company is able to reuse the materials in their own processes. In other cases, the polyethylene (fibers) and polypropylene (fiber backing) materials can be re-pelletized and uses in new product applications. FieldTurf says they have made a significant investment in their business to facilitate the recycling of their products and they have established cooperative partnerships with leading "pelletizers" to accelerate the process over the next several years. FieldTurf has several patents pending from their recycling R&D efforts.

Page 18 details how the ten FieldTurf fields that have been replaced have been recycled and offers examples of future applications under development by the company. The surface materials at Maple Park will not go to a landfill, when the field reaches the end of its useful life.

Given the small number of fields that have been replaced, the recycling of “old fields” is in its infancy. However, over the next decade, as the supply of recyclable materials from synthetic fields becomes greater, the opportunities will expand.

Synthetic Grass Fibers (polyethylene)

The fibers can be ground up and sold to “re-pelletizers”, who produce raw material “pellets”. Polyethylene is the most common plastic in the world and is used to make many of the products we use every day. FieldTurf is developing applications for the fibers to be made into garbage cans and park benches (similar to those at Maple Park).

Fiber Backing (polypropylene)

The fiber backing can also be ground up and sold to “re-pelletizers”, who produce raw material “pellets”. There are thousands of household and automotive applications for these pellets, including T-shirts and bags. FieldTurf re-manufactures the backing into its FieldTurf Armor, which is a hard plastic cover used to protect the field surface in some multi-use field installations. FieldTurf has formed strategic partnerships to drive recycling demand for the backing. This material can also be used as road base fill.

Sand

The sand from field is currently being used as top fill on grass fields, road base fill and ballast in highway crash barriers. After being sanitized with UV light, it is also re-used on new FieldTurf fields. There is no practical limit to the number of times the sand can be recycled in a new field.

Cryogenic SBR (rubber)

The cryogenic rubber from field is currently being used as road base fill, ballast in highway crash barriers and, after being sanitized with UV light, it is repackaged and re-used on new FieldTurf fields. The rubber will maintain its beneficial characteristics for approximately 25 years in a field. Therefore, FieldTurf expects to be able to re-use the the same cleaned rubber on 2-3 different fields before recycling it as road base fill or in similar applications.

FieldTurf's Statement on 100% Recyclability

8) Does the surface at Maple Park harm the environment by eliminating the normal CO^2 absorption of natural grass?

It is well known that grass, plants and trees absorb CO^2 from the atmosphere and sequester carbon in their roots, stalks and trunks. Larger and faster growing organic systems, such as pine trees, are particularly effective in this regard. So, it is logical to assume that the synthetic surface at Maple Park would reduce the healthy absorption of CO^2 in the area.

The absorption of CO^2 is only half of the carbon cycle with plants and grasses. Gardeners and turf managers know that, when these systems decay, they release nutrients into the soil, and heat and sequestered carbon, in the form of CO^2, back into the atmosphere. This is the principle behind "grass cycling" or allowing grass clippings, which decay rapidly, to remain in the grass as a natural fertilizer. Furthermore, with grass in Ridgewood, the carbon sequestration process primarily occurs during the growing seasons (not year-round). The final issue is the health of the grass. Lush thick grasses will absorb more CO^2 (and give more back when mowed). However, fields with large dirt areas and thinned, over-stressed grass absorb and give off a comparatively small amount of CO^2.

A 2008 article in the Boston Globe discusses the organic decay process when describing Boston's plans to harness the biogases released in this process to generate "environmentally friendly" electricity. Jerry Hannan, PhD, a retired researcher from the Naval Research Laboratories in Washington, D.C., who now works with the Environmental Protection Agency, cautions people to keep the issue of carbon sequestration in perspective. He states that "grass absorbs CO^2 but only on a short term basis. Grass clippings decompose or are eaten, but in a relatively short time much of the carbon is released back into the atmosphere as CO^2."

As a result, natural grass fields that are mowed regularly (Maple Park was mowed once per week for 36 weeks out of the year) offer no meaningful "net" CO^2 absorption. According to the Cornell University Turfgrass Times *(2008 Issue 2, Volume 19, Number 2),* a newsletter published by the New York Greengrass Association, "managed turf (such as a golf course) is a carbon sink. Trees are an even greater carbon sink. Native vegetation and grassland is neutral."

Large trees and bodies of water, such as oceans, are the primary storehouses of CO^2. Lawns and grass athletic fields are approximately carbon neutral. As is also evident in the video, which documents the construction at Maple Park, the former field had large areas of bare dirt and was not a lush grass field during the spring and fall growing seasons. This would have further diminished the effectiveness of CO^2 absorption at Maple Park. While the new surface at Maple Park is synthetic, the previous grass field would have had a low CO^2 absorption rate and, like all athletic fields, would have been approximately carbon neutral due to the normal carbon cycle. REAC believes that the new surface at Maple has resulted in a negligible net decline in CO^2 absorption.

It was also pointed out that five rotting trees (net producers of CO^2) were removed at the site along with scrub brush (which died every fall) along the east side of the park. These were replaced with thick grasses and thriving new gardens, including 15 fast growing Norwegian Spruce trees. The new trees are 15'-18' tall and will grow to about 50'. These landscaping changes are not part of the turf design. But, they provide a "net gain" in CO^2 absorption at the park, as a result of the project. According to the Department of Parks and Recreation, the new landscaping was a critical component in the plan to revitalize and beautify Maple Park. "The new field surface and landscaping were complementary and were part of the plan from day one", said Tim Cronin. The whole park is now more attractive, more functional and more environmentally friendly. As a result, a grant was received to extend the landscaping between Maple Park and Graydon Pool. That project was completed in the fall of 2009.

If Ridgewood considers additional synthetic fields in the future, REAC strongly recommends that beneficial landscaping be required as part of the project(s). REAC believes that it is possible to complement Ridgewood's natural grass fields with synthetic fields in an environmentally sensitive way that also can improve the aesthetics of the surrounding area, as was done at Maple Park.

Boston: Urban Decay Redefined 2008
Cornell University Turfgrass Times (CUTT)
J. Hannan 1997 - Your Role in the "Greenhouse Effect" (in response to public ignorance on scientifc matters)
"Photosynthesis" - David Oakly Hall & K.K. Rao, Institute of Biology
Maple Park Construction Video

9) Is the field design at Maple Park suitable in the flood plain?

To understand why one would consider locating a synthetic field in a flood plain, REAC summarized the fundamental need for athletic fields in Ridgewood. Most of Ridgewood's largest and most heavily used athletic fields (Maple Park, Veterans Field, Stevens Field, RHS Stadium Field and Brookside Field) lay in a flood plain. In the early 1900s the current site of Veterans Field, Stevens Field and RHS Stadium Field were the site of the Ridgewood Golf Club and the area between Stevens Field and RHS Stadium Field was a swamp that was converted to a large pond. Due to rapid residential development around this area in the following years, available land for athletic field use was limited. This condition still exists 100 years later.

However, the demand upon the fields has expanded exponentially in the last 20 years and continues to grow. According to page 20 in Schoor DePalma's report to Ridgewood in the latest draft of the Comprehensive Parks, Fields, Facilities and Recreation Master Plan (June 23, 2008), "the combined acreage (for park and active recreation space) of the Village park system properties, Board of Education properties, and County facilities/parks…cannot adequately support the existing or future population." The conclusion was based on the National Recreation and Park Association Core System calculation, which showed that Ridgewood had only 80% of the necessary acreage. According to Schoor DePalma, this condition is compounded by the fact that Ridgewood's school age population is 25%, as compared to the national average of 18%, and Ridgewood has one of the largest combined youth sports programs in NJ. With no new acreage available, the response has been to consider ways to use existing fields more efficiently. This was the motivation to convert Maple Park to a synthetic surface, before the Schoor DePalma recommendations were made.

Latest Version of Ridgewood Master Plan - June 23, 2008 (takes several minutes to download)

REAC took a step back to understand what issues a flood plain presents for an athletic field. Because of the flood plain location, these fields are not usable much of the time. The average monthly precipitation when the fields are in use is 4.51" and, according to the sports organizations in town, it is not uncommon for the fields to be closed for 30% or more of their scheduled time on the various fields in a season.

Maple Park's old drainage system consisted of a French Drain perimeter drain system with a single collection point that drained into the Ho-Ho-Kus Brook. There was no "crown" on the field to allow water to flow toward the perimeter. Because of the flood plain, the water table at Maple Park is shallow (36"-50" below the surface) and the field was quickly saturated, causing inefficient drainage. Ridgewood was required to conduct an engineering study at Maple Park prior to NJDEP approval of the project. According to the engineering study performed by Neglia Engineering Associates in July 2005, the soil samples exhibited slow surface runoff. Like all the fields in the flood plain, this left Maple Park vulnerable to damage from over-usage, caused by the shortage of fields and demand from Ridgewood's above average school age population. In their presentation, titled, "Natural Grass Athletic Fields for High Schools", The Sports Turf Managers Association (STMA), an industry group that advocates the use of natural grass fields, notes that standing water and overusage are problems with grass athletic fields in parks, schools and colleges that can "lead to compaction and bare areas, which can cause a surface to be unsafe and unplayable." The Maple Park Construction video shows this is precisely the condition that existed with the old grass field. According to, Dr. A.J. Powell, a natural grass advocate and turfgrass agronomist with the University of Kentucky, "the fact is, we have never been able to manage grass that would take the kind of wear we now want to give it."

Flood conditions are not required for our flood plain fields to become "unplayable". However, in flood conditions, which occur every 1-2 years in Ridgewood, fields in the flood plain may be unplayable for several days, while the surface at Maple Park has been playable within hours after flooding. During normal heavy rains that routinely close our grass fields there has been no disruption of use at Maple Park.

Sports Turf Managers Association
Maple Park Construction Video

REAC wanted to know what makes this possible and reviewed the design of the field at Maple Park.

The new field at Maple Park is surrounded by a 12” high concrete curb. The natural soil inside the curb was compacted to 95% Proctor and graded. The surface of the natural soil is about 1” above the bottom edge of the curve. A couple of feet inside the curb, a 2’-3’ perimeter drainage trench was dug (total of 1,650’ of trench included a section under the baseball field). A non-woven geotextile lining that filters soil particles and allows water to flow through is laid on top of the natural soil and the perimeter drainage trench surface. In effect, this created a large “tub” to hold water and drain into the water table at a controlled rate.

A 6” foundation of large stone fill was then compacted in the trench and an 8” perforated drainage pipe was laid into the trench with 42 connection points. Sleeves extend at an angle from the connection points to the height of the natural soil beneath the field surface. The remainder of the drainage trench was filled with large stone fill and compacted, leaving the sleeve ends exposed.

Then 4,140’ of flat drain channel membrane (1” X 12”) was laid across the surface in a herringbone pattern and connected to the perimeter drain sleeves. Once the drainage connections were complete, the entire tub inside the curb was filled with approximately 6” of compacted and graded large stone fill. Above that is a 2” layer of fine top stone, which was compacted and graded to the design specifications with a laser guided grader. This is the permanent portion of the drainage system.

The synthetic fibers (2.5”) and backing are laid on the top stone, stretched and secured to the curb. Then several layers of sand are tufted into the fibers (approx 0.25”). Then an equal mix of similarly sized cryogenic rubber and sand are tufted into the fibers (approx. 1”) with alternating layers. Finally, a top layer of slightly larger sized cryogenic rubber is tufted into the fibers (approx. 0.5”). The infill process required approximately 20 layers of sand and rubber infill. The completed field and drainage system at Maple Park is essentially a 95,000 square foot water detention basin with a total volume of approximately 105,000 cubic feet below the infill layers.

Neglia Engineering Associates’ study calculated peak storm water runoff rates of 0.65cfs for a 2-year storm event and 3.08cfs for a 10-year storm event. The new storm water design resulted in peak storm water runoff rates of 0.03cfs for a 2-year storm event and 0.18cfs for a 10-year storm event.

There are several keys to Maple Park's ability to handle large volumes of water in a short period of time, while dramatically reducing the storm water runoff rates. First, according to FieldTurf, the system drains much more effectively than the previous natural soil because of the 8" stone base below the sand and rubber infill. Secondly, the drain channels below the stone base can rapidly move the water to the perimeter drain trenches. Thirdly, as the water flows into the perimeter drain trenches, it is stored there and drains slowly into the water table until approximately 8" of water (approximately 20,000-25,000 gallons) has collected in the trench. Only then does the water begin to flow into the drainage pipes and into the Ho-Ho-Kus Brook. Finally, the stone base under the field has the ability to hold hundreds of thousands of gallons of water. This means that a significant amount of water will be contained in the stone base beneath the field before the drainage trenches approach a level, at which they will begin to drain. The result is that during most rain events in Ridgewood, Maple Park does not drain any water at all into the Ho-Ho-Kus Brook. It should be noted that a natural grass field could employ a similar drainage design to achieve similar drainage results, particularly if the top soil blended with sand and is routinely top dressed with new sand. However, the previously noted environmental benefits of the turf surface would not be realized. None of Ridgewood's grass fields employs the sophisticated drainage system used at Maple Park.

Neglia Engineering Associates' engineering study summarized the storm water design as follows. The design premise will "provide temporary storage and will facilitate infiltration. Rainfall that would otherwise runoff the grassed areas is retained on site for a longer period of time, thus allowing more water to be infiltrated during small storm events. During larger storm events, or 'back to back' small storms, the area will act as a small detention basin and will discharge to the existing storm water collection system upon reaching saturation, in a manner similar to the existing grassed field."

Based on REAC's understanding of the "engineered" storm water management system at Maple Park, REAC believes it is a significant improvement over the previous natural soil and French Drain system. The significant reduction in runoff rates is a clear indication of the site's ability to handle vastly greater quantities of storm water over shorter periods of time. While extreme events can still cause the site to flood, this is due to conditions where the Ho-Ho-Kus Brook breaches its banks, rather than saturation of site itself. This condition is infrequent. Although, as we have witnessed in 2007, when it does occur, the new storm water design will accommodate the flood water in a matter of hours and be available for use with minimal disruption.

Cascia Hall Preparatory School in Tulsa has a multi-decade history of catastrophic flooding with its football field along the Arkansas River. In September 2007 they installed a FieldTurf field. Their experience in “the strictest flood control district in the country” (see link below) supports the belief that the storm water design at Maple Park will continue to be effective in our conditions.

As a final note, REAC was concerned that the rubber infill will wash off the field during storm events. In reality, the cryogenic rubber used at Maple Park does not float, since air pockets are eliminated during the cryogenic process. If a condition of “rushing water” existed, it might be possible for a small amount of rubber to be carried off the surface, similar to sand or dirt. However, overflow from the Ho-Ho-Kus Brook does not create a “rushing water” condition at Maple Park or any of the fields in the flood plain. Therefore, REAC does not believe that this represents a basis for environmental concern in Ridgewood.

One issue that was raised by the sports groups and RHS coaches was that overflow conditions could result in debris being deposited on the field surface. According to FieldTurf, such debris should be removed from the surface as soon as possible, as with grass fields. If dirt is deposited into the infill, it can reduce the drainage capacity advantage of the field over natural grass. If addressed promptly, this condition is easily corrected with the proper maintenance equipment. The Department of Parks and Recreation confirmed that they have the necessary equipment to deal with this issue and are aware of the proper procedure. Simple routine grooming and maintenance once or twice a season is required to keep the field surface in peak condition,depending on usage.

In conclusion, REAC believes that the synthetic turf and drainage system at Maple Park is a viable alternative to natural grass fields in Ridgewood’s flood plain. Furthermore, the Village’s experience at Maple Park demonstrates that there are significant environmental and functional advantages with this system over the previous natural grass field. Based on the experience at Maple Park, there does not appear to be evidence for environmental concern about these fields in Ridgewood’s flood plain.

"Winning Over the Skeptics" - Athletic Facility Design (FieldTurf case study reprint)
Maple Park Construction Video

APPENDIX

Ridgewood Environmental Advisory Committee (REAC)
Evaluation of Temperature Measurements at Recreational Facilities
in Ridgewood, NJ

July/August 2009

CONCERNS

Media attention during 2008 in New York, Connecticut and New Jersey regarding the potential dangers of heat exposure from synthetic turf fields has added new fuel to the debate over the popularity of synthetic fields. It has been asserted that synthetic fields in New York City are "heat islands" that can reach 160 ºF, contributing to global warming. Even the world's leading manufacturer of synthetic fields admits that the surface temperatures on their fields can be higher than surface temperatures for natural grass under similar conditions.

Given Ridgewood's proximity to New York City, REAC was alarmed by claims of temperatures in excess of 160º F. REAC measured the temperature at Maple Park in comparison to other recreational surfaces in Ridgewood under "high heat" conditions in July and August, in order to document actual results "from our own experience". The testing methodology is summarized in the background information on page 28. REAC's concerns are detailed simply below:

A. Does the synthetic turf surface at Maple Park in Ridgewood, NJ reach temperatures, which might pose an unusual health risk for athletes and spectators, particularly youth athletes? If so, should special precautions be undertaken at Maple Park?

B. Do elevated ambient air temperatures from the surface at Maple Park pose an environmental concern, when compared to the natural grass at the RHS Stadium Field?

BACKGROUND INFORMATION

Outdoor recreational facilities in Ridgewood, NJ are used from March through November, with highest usage during six school months in the spring (March - June) and fall (September - November).

Ridgewood's record high temperature is 102ºF, recorded in July 1966. [1]

June through September have the highest "record" temperatures in Ridgewood (average "record" in this period is 99ºF). Ridgewood has not seen a new record high during any of these months in over 21 years.[1] The average "mean" temperature during these months is 69ºF. The average "high" temperature during these months is 89ºF.

- **June:** Average Mean = 68ºF / Average High = 79ºF / Record High (1957) = 98ºF
- **July:** Average Mean = 73ºF / Average High = 84ºF / Record High (1966) = 102ºF
- **August:** Average Mean = 71ºF / Average High = 82ºF / Record High (1988) = 98ºF
- **September:** Average Mean = 64ºF / Average High = 75ºF / Record High (1980) = 98ºF

Average monthly rainfall in Ridgewood from March through November is 4.51". Highest average is May (5.14").[1]

No "heat related" injury, resulting from high surface temperature on any surface, was reported to REAC by Ridgewood High School or Ridgewood youth sports groups during this 10-month study. It is REAC's understanding that no such injury has been reported at Maple Park, since the installation of the synthetic surface in 2006.

REAC evaluated five different facilities, representing outdoor recreational surfaces used in Ridgewood:

- Ridgewood High School Tennis Courts (asphalt)
- Ridgewood High School Running Track (rubberized surface)
- Ridgewood High School Stadium Field (natural grass)
- Maple Park Field (synthetic "infill" turf)
- Maple Park/Graydon Parking Lot (black top asphalt similar to roadways used by joggers)

Temperature readings were taken on three days between July 5th and August 15th (2009). Days with near or above average temperatures and bright sun were selected to sample "worst case" scenarios. Three simultaneous measurements were taken; **1)** surface temperature (infrared reading), **2)** 12" height above the surface (thermometer) and **3)** 39" height above the surface (thermometer). The measurements were taken close to highs for the day within 45 minutes of each other and the sequence of the measurements was different on each day. The 39" height was intended to approximate the chest/head height of an elementary school age athlete. The air temperature on the three days ranged from 81ºF to 94ºF. The average was 86.3ºF, which exceeds the average monthly "mean" temperature for June through September in Ridgewood above by 25% and exceeds the Average "high" by 7.87%. [1, 2]

1) Source: *The Weather Channel - Ridgewood, NJ Monthly Averages* , *The Weather Channel - Ridgewood, NJ Monthly Mean Table*
2) The measurements were taken with two Taylor outdoor thermometers and a General Tools digital infrared thermometer heat gun

FINDINGS

(for details, see video links, table and chart on pages 32-34)

- The highest surface temperatures were recorded at the RHS Tennis Courts (148ºF) and RHS Track (137ºF). The average surface temperatures at these locations were up to 14.8% hotter than the average surface temperature at Maple Park (114.4ºF).
- Natural grass at the RHS Stadium Field had the lowest average surface temperature (87.4ºF). The natural grass field was also the only surface, which had average ambient air temperatures above the surface, which were <u>higher</u> than the average surface temperature.
- Shoe soles (particularly rubber-sole sneakers, cleats, etc.) insulate virtually all surface heat and no difference in surface temperature or discomfort was "felt" by the evaluators on any of the surfaces on any day. [1, 2]
- At heights of 12" and 39" above the surface, the average ambient air temperatures measured at all five facilities were between 4 - 12ºF higher than the average general air temperature.
- Despite the wide variance in average surface temperatures, the difference in average ambient air temperatures measured above ALL the surfaces were within 8ºF of each other at 12" above the surface and within 5ºF of each other at 39" above the surface. The average air temperature cooled dramatically within a few inches above the surface. The average air temperature was over 17.5% lower than the surface temperature at 12" above the surface and almost 18% lower at 39" above the surface.
- The average ambient air temperatures measured at the natural grass at the RHS Stadium Field and the surface at Maple Park Field were virtually identical (within 3ºF) at heights of both 12" and 39" above the surface. These differences were undetectable without thermometers.
- Partial clouds, light wind (and rain) can significantly lower the surface temperature on natural grass and synthetic turf. The more exposed a surface is (lack of trees or structures surrounding the surface), the greater the effect tends to be, particularly from wind. Under any combination of these conditions, the ambient air temperatures of natural grass and synthetic turf tended to be more similar in our measurements.

1) The sole of the the shoes insulated the surface temperature from the feet.
2) On July 12th, the highest surface temperatures were measured at Maple Park (127.5ºF). However, a number of children were playing wiffle ball on the synthetic turf surface in bare feet and reported no discomfort when asked if it was too hot (see video).

CONCLUSIONS

- REAC's average measurements indicated that the surface at Maple Park Field was 35% (approx. 30ºF) hotter than the natural grass surface at the RHS Stadium Field, under similar conditions.
- The average measurements indicated that the surfaces at the RHS Tennis Courts and the RHS Track, two frequently used and well accepted recreational facilities (from a safety perspective), were 50% (44ºF) hotter than the natural grass surface at the RHS Stadium. This has never been a health, safety or environmental problem in Ridgewood.
- The ambient air above the surfaces is a result of air temperature and radiated heat (from the sun and the surface). Thus, the ambient air determines an athlete's or spectator's "perception of heat." Our evaluation clearly showed that the surface temperature, by itself, has little impact. Thus, concern over elevated surface temperature appears to be misleading. REAC's average ambient air measurements at each facility were consistently similar, regardless of the surface type or temperature. In particular, the measurements taken at 12" and 39" above the natural grass at the RHS Stadium Field and the surface at Maple Park Field were extremely similar. The average difference was 3ºF or less. A contributing factor may be the high trees, which surround Maple Park providing more wind blockage than at the RHS Stadium Field. The negligible differential in the ambient air measurements do not suggest any basis for health or safety concern between the two surfaces.
- The ambient air temperature above the surface at Maple Park appears normal and does not suggest a basis for environmental concern that would have an adverse impact on the surrounding area.
- Experts agree that synthetic surfaces will be hotter than natural surfaces for several reasons. The specific relative temperatures are a direct function of the local climate conditions. Unlike other parts of the country, Ridgewood's seasonal climate has only resulted in air temperatures in excess of 100ºF once in the last 100 years. It is unrealistic to expect surface temperatures to approach those reported in hotter climates. The surface and ambient air temperatures above the surface at Maple Park are well within the historically acceptable and safe levels experienced at other recreational surfaces in Ridgewood and, thus, do not reach levels that appear to be abnormal or unsafe. REAC's documented measurements of the surface at Maple Park sharply contrast with claims that have been publicized in the local press in recent years about synthetic turf.

CONCLUSIONS

- REAC took measurements during periods of above average daily temperatures in Ridgewood (average temperature was 25% above the mean temperature for June, July, August & September) and found no evidence to suggest that the surface at Maple Park generates a heat condition that poses an unusual health risk to athletes or spectators even under these elevated summer conditions.
- Under historically experienced conditions during the fall and spring months when Maple Park Field is most heavily used, REAC expects the ambient air and the surface temperatures at Maple Park Field to be considerably lower than were measured in this evaluation and, further, to be normal and similar to that of natural grass at other fields in Ridgewood. Therefore, REAC recommends that, during periods of unusually high temperatures, the same precautions to reduce heat exposure and remain hydrated that are followed on any natural grass field also be followed at Maple Park. There is no need to cool the field surface itself.

VIDEO DOCUMENTATION/COMMENTARY OF MEASUREMENTS

Video Links:

July 5, 2009 Temperature Readings

July 12, 2009 Temperature Readings

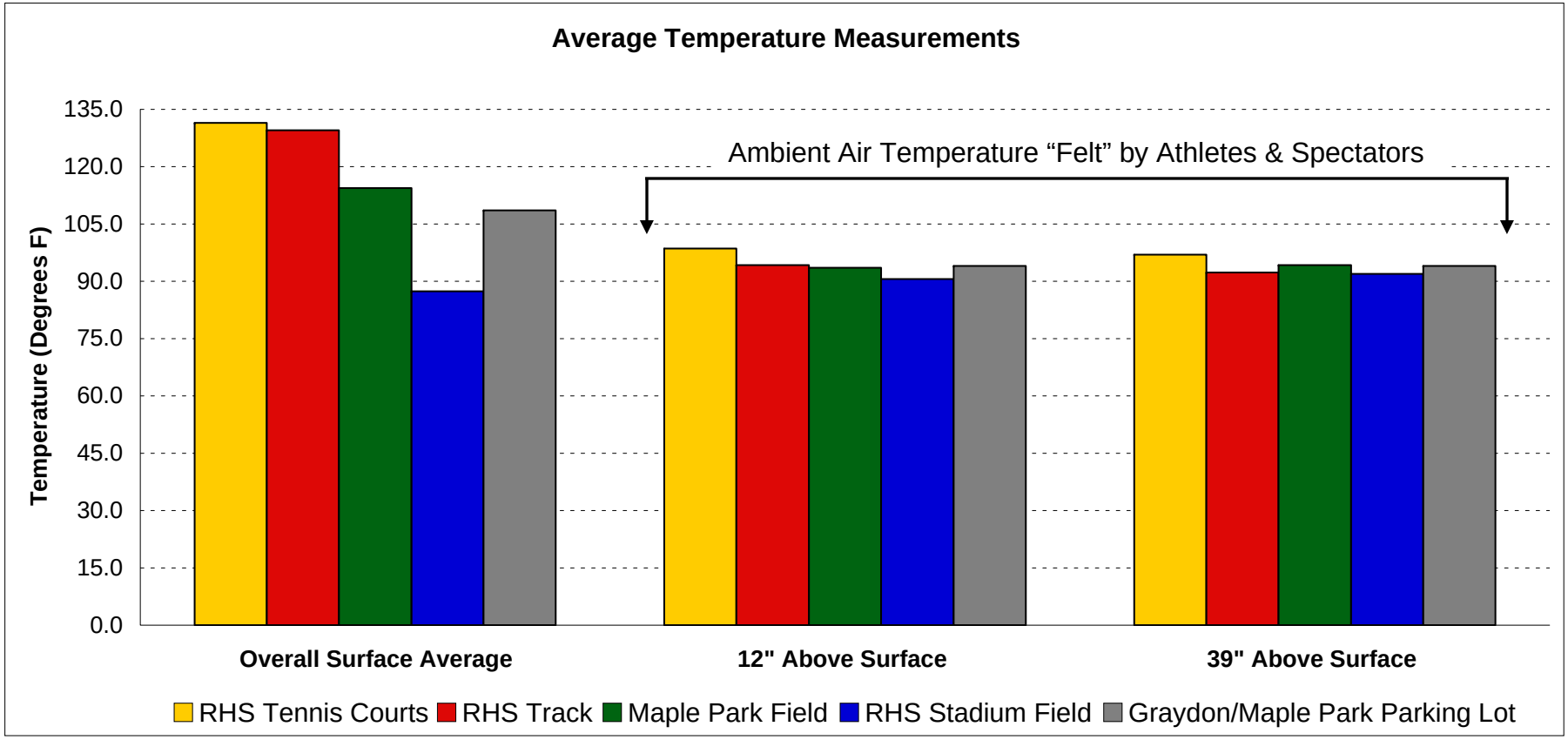
August 15, 2009 Temperature Readings

Additional Links:

Brigham Young Surface Temperature Study 2002

Milone & MacBroom Environmental Study 2009

LOCATION	RHS TENNIS COURTS	RHS TRACK	MAPLE PARK FIELD	RHS STADIUM FIELD	MAPLE/GRAYDON PARKING LOT
JULY 5, 2009					
Surface Type	**Asphalt**	**Rubberized**	**FieldTurf (October 2006)**	**Natural Grass**	**Asphalt (black top)**
Air Temperature	**81° F**	**81° F**	**81° F**	**81° F**	**81° F**
Weather	**Bright Sun/Scattered Clouds**	**Bright Sun/Scattered Clouds**	**Bright Sun/Scattered Clouds**	**Bright Sun/Scattered Clouds**	**Bright Sun/Scattered Clouds**
Wind	**Light**	**Light**	**Light**	**Light**	**Light**
Time	**2:20PM**	**2:35PM**	**2:50PM**	**2:40PM**	**3:05PM**
Surface "RED" (infrared digital meter)	135.5° F	134.5° F	102.5° F	N/A	N/A
Surface "WHITE" (infrared digital meter)	112° F	N/A	101° F	N/A	N/A
Surface "GREEN" (infrared digital meter)	136.5° F	N/A	106° F	77.9° F	N/A
Surface "BLACK TOP" (infrared digital meter)	N/A	N/A	N/A	N/A	114° F
12" Above Surface (outdoor thermometer)	94° F	91.5° F	86.5° F	86° F	94° F
39" Above Surface (outdoor thermometer)	92° F	88° F	86.5° F	86° F	92° F
JULY 12, 2009					
Surface Type	**Asphalt**	**Rubberized**	**FieldTurf (October 2006)**	**Natural Grass**	**Asphalt (black top)**
Air Temperature	**84° F**	**84° F**	**84° F**	**84° F**	**84° F**
Weather	**Bright Sun/No Clouds**	**Bright Sun/No Clouds**	**Bright Sun/No Clouds**	**Bright Sun/No Clouds**	**Bright Sun/No Clouds**
Wind	**Breezy**	**Breezy**	**Breezy**	**Breezy**	**Breezy**
Time	**12:45PM**	**12:40PM**	**12:15PM**	**12:35PM**	**12:25PM**
Surface "RED" (infrared digital meter)	134.5° F	117° F	N/A	N/A	N/A
Surface "WHITE" (infrared digital meter)	114° F	N/A	N/A	N/A	N/A
Surface "GREEN" (infrared digital meter)	132.5° F	N/A	127.5° F	88.5° F	N/A
Surface "BLACK TOP" (infrared digital meter)	N/A	N/A	N/A	N/A	88.5° F
12" Above Surface (outdoor thermometer)	93° F	88° F	90.5° F	88° F	88° F
39" Above Surface (outdoor thermometer)	89° F	86° F	90° F	88° F	88° F
AUGUST 15, 2009					
Surface Type	**Asphalt**	**Rubberized**	**FieldTurf (October 2006)**	**Natural Grass**	**Asphalt (black top)**
Air Temperature	**94° F**	**94° F**	**94° F**	**94° F**	**94° F**
Weather	**Bright Sun/Partly Cloudy**	**Bright Sun/Partly Cloudy**	**Bright Sun/Partly Cloudy**	**Bright Sun/Partly Cloudy**	**Bright Sun/Partly Cloudy**
Wind	**Light**	**Light**	**Light**	**Light**	**Light**
Time	**3:02PM**	**2:50PM**	**3:14PM**	**2:56PM**	**3:10PM**
Surface "RED" (infrared digital meter)	146° F	137° F	118.5° F	N/A	N/A
Surface "WHITE" (infrared digital meter)	126.5° F	N/A	N/A	N/A	N/A
Surface "GREEN" (infrared digital meter)	145.5° F	N/A	121.5° F	95.7° F	N/A
Surface "BLACK TOP" (infrared digital meter)	N/A	N/A	N/A	N/A	123.5° F
12" Above Surface (outdoor thermometer)	109° F	103° F	104° F	98° F	100° F
39" Above Surface (outdoor thermometer)	110° F	103° F	106° F	102° F	102° F
3 DAY AVERAGE					
Surface Type	**Asphalt**	**Rubberized**	**FieldTurf (October 2006)**	**Natural Grass**	**Asphalt (black top)**
Air Temperature	**86.3° F**	**86.3° F**	**86.3° F**	**86.3° F**	**86.3° F**
Weather	**Bright Sun/Partly Cloudy**	**Bright Sun/Partly Cloudy**	**Bright Sun/Partly Cloudy**	**Bright Sun/Partly Cloudy**	**Bright Sun/Partly Cloudy**
Wind	**Light**	**Light**	**Light**	**Light**	**Light**
Time	**2:02PM**	**2:01PM**	**2:06PM**	**2:03PM**	**2:13PM**
Surface "RED"	138.6° F	129.5° F	110.5° F	N/A	N/A
Surface "WHITE"	117.5° F	N/A	N/A	N/A	N/A
Surface "GREEN"	138.2° F	N/A	118.3° F	87.4° F	N/A
Surface "BLACK TOP"	N/A	N/A	N/A	N/A	108.6° F
OVERALL SURFACE AVERAGE	**131.4° F**	**129.5° F**	**114.4° F**	**87.4° F**	**108.6° F**
12" Above Surface	**98.6° F**	**94.2° F**	**93.6° F**	**90.6° F**	**94° F**
39" Above Surface	**97° F**	**92.3° F**	**94.2° F**	**92° F**	**94° F**


Average Temperature Measurements
Temperature (Degrees F)
135.0
120.0
105.0
90.0
75.0
60.0
45.0
30.0
15.0
0.0
Ambient Air Temperature "Felt" by Athletes & Spectators
Overall Surface Average
12" Above Surface
39" Above Surface
RHS Tennis Courts
RHS Track
Maple Park Field
RHS Stadium Field
Graydon/Maple Park Parking Lot

Full List & Additional Informational Links of Interest

Penn State Center for Sports Surface Research
FieldTurf Product Overview
Maple Park Construction Video
Sports Turf Managers Association
Latest Version of Ridgewood Master Plan - June 23, 2008 (takes several minutes to download)
Boston: Urban Decay Redefined 2008
Cornell University Turfgrass Times (CUTT)
J. Hannan 1997 - Your Role in the "Greenhouse Effect" (in response to public ignorance on scientifc matters)
"Photosynthesis" - David Oakly Hall & K.K. Rao, Institute of Biology
NYC Scientific Panel Discussing "Absurdly Unrealistic" Risk of Lead Exposure - May 5, 2008
Brian Williams on NBC: Turf is Safe According to CPSC - July 30, 2008
"The Record" Reverses and Reports Turf Not Dangerous - Franklin Lakes, NJ - July 30, 2008
NY Department of Environmental Conservation Crumb Rubber Infilled Field Report - May 2009
Clean Washington Center (CWC) Best Practice - Ambient vs. Cryogenic Grinding
FieldTurf Q6 Quality Control
CA Office of Environmental Health Hazard Assessment (CA EPA) - July 2009
U.S. EPA Website - Sources of Nonpoint Pollution
Potential LEED Credits for FieldTurf Installations
"Winning Over the Skeptics" - Athletic Facility Design (FieldTurf case study reprint)
"LEED-ing the Way" - Athletic Facility Design (FieldTurf case study reprint)
NY Department of Health Fact Sheet On Rubber In Filled fields
Milone & MacBroom Comprehensive Turf Study 2009
King County (Seattle) Water & Land Resource Division Evaluation of Environmental Risks
Penn State MRSA Study
NBC News Report (Dublin, OH) on AJSM Article Concluding That Natural Grass Causes More Serious Injuries Than Turf
5-Year Meyers & Barnhill Texas HS Football Study 2004 - American Journal of Sports Medicine, Vol. 32, No. 7
2-Year NCAA Soccer Study 2007 - British Journal of Sports Medicine
FieldTurf Maximum Safety & Performance (MSP) Standard Video
FieldTurf's Statement on 100% Recyclability
The Weather Channel - Ridgewood, NJ Monthly Averages
The Weather Channel - Ridgewood, NJ Monthly Mean Table
July 5, 2009 Temperature Readings
July 12, 2009 Temperature Readings
August 15, 2009 Temperature Readings
Brigham Young Surface Temperature Study 2002

REAC Synthetic Turf Assessment Sub-Committee (alphabetical)

Bayard DeMallie	- Vice President, Morgan Stanley - Worked extensively with Maple Park renovation effort
Robin Gardner, CEC	- President, Phoenix Life Coaching - Member of Ridgewood Chamber of Commerce - Developed REAC Consumer Guide for Selecting Landscaping Contractors
John Halenar	- Environmental writer and consultant (clients include Amtrak, the Gaia Institute, Scenic Hudson, and the New York State Recycling Association - Former Manager of Environmental Issues, Verizon Information Services
Michele Lenhard	- Ridgewood Board of Education Representative to REAC
George Wolfson	- Retired from Waste Management - Over 30 years experience in business development and general management in the recycling and maritime transportation industries

Chemicals and particulates in the air above the new generation of artificial turf playing fields, and artificial turf as a risk factor for infection by methicillin-resistant *Staphylococcus aureus* (MRSA)
Literature review and data gap identification

Office of Environmental Health Hazard Assessment
California Environmental Protection Agency
July, 2009

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Executive Summary

The Office of Environmental Health Hazard Assessment (OEHHA) is evaluating the safety of the new generation of artificial turf playing fields. This new generation of turf contains artificial soil termed "infill." Infill helps to soften the surface and prevent injuries. Infill also improves drainage.

Rubber crumb made from finely ground, recycled tires is commonly used as infill in the new generation of artificial turf. Tire rubber is a complex material, containing many naturally-occurring and man-made chemicals. Therefore, as part of its stewardship of tire recycling in California, the California Integrated Waste Management Board (CIWMB) has asked OEHHA to evaluate the following aspects of artificial turf playing fields:

1. Whether these fields emit levels of chemicals or particulates into the air that cause illness when inhaled.
2. Whether these fields infect athletes with the dangerous bacterium called methicillin-resistant *Staphylococcus aureus* (MRSA).

The following is our review of the published literature covering these two topics. In addition, we have attempted to identify data gaps that, when filled, will allow performance of a more accurate safety assessment.

Chemicals and Particulates Measured in the Air Above Artificial Turf Fields

Published studies were located that measured chemicals and particulates in the air above artificial turf playing fields. In all cases these fields contained crumb rubber infill. Prior to 2009, the most complete dataset was published by Dye et al. (2006). They identified almost 100 different chemicals and particulates. Another 200 chemicals were detected but not identified. This study covered fields in ***indoor*** stadiums.

Many of the chemicals identified by Dye et al. (2006) were also emitted into air by rubber flooring made of recycled tires. Similarly, laboratory studies of chemicals emitted into the air by crumb rubber made from recycled tires identified many of the same chemicals. A list of the chemicals and particulates emitted into the air during rubber manufacturing also overlapped with those identified by Dye et al. (2006). Therefore, the published literature suggests the data from Dye et al. (2006) are reliable.

In the spring of 2009 two studies were released that measured chemicals and particulates in the air above ***outdoor*** artificial turf fields containing recycled rubber crumb (New York State, 2009; TRC, 2009). Both studies targeted the same two fields in New York City. Totals of 65 and 85 chemicals were identified at relatively low concentrations in the air above the two fields. Many of these occurred at similar concentrations in the air sampled upwind of the fields. Concentrations of particulates above the fields were similar to the levels upwind of the fields. Both reports concluded that these fields did not constitute a serious public health concern, since cancer or non-cancer health effects were unlikely to result from these low-level exposures.

A comparison of the chemicals detected in the air above the same two artificial turf fields that comprised the studies by New York State (2009) and TRC (2009) shows that chemical concentrations were consistently higher in the New York State (2009) study, ranging from 1.7-fold to 85-fold higher. The reasons for these differences are unknown. These variable results highlight the difficulties faced in obtaining consistent results from potential point sources of outdoor air pollution. Despite this variability, both studies found that the chemical concentrations they measured were unlikely to produce adverse health effects in persons using these fields.

Is the Air Above Artificial Turf Fields Hazardous to Human Health?

OEHHA constructed a test scenario for an athlete playing soccer from ages 5 to 55 years on the new generation of artificial turf fields containing crumb rubber infill. The data from Dye et al. (2006) were used for chemical concentrations in the air above the fields, since this was the most comprehensive data set available at the time. Breathing rates were based on published data. Time spent on the fields for soccer games and practices was estimated.

From among the chemicals identified by Dye et al. (2006), eight appear on the California Proposition 65 list of chemicals known to the state to cause cancer. Exposure to five of these via inhalation (benzene, formaldehyde, naphthalene, nitromethane, styrene) gave increased lifetime cancer risks that exceeded one in one million (10^{-6}), generally considered the negligible risk level. In other words, more than one cancer case could be expected to occur in a hypothetical population of one million people regularly playing soccer on these artificial turf fields between the ages of 5 and 55. The highest risk was from nitromethane, which could cause about nine cancer cases in a hypothetical population of one million soccer players. While these estimated risks are low compared to many common human activities, they are higher than the negligible risk level of one cancer in a population of one million people. Data gaps exist that could lead to overestimates or underestimates of these risks.

Two of the chemicals identified by Dye et al. (2006) appear on the California Proposition 65 list as developmental/reproductive poisons (toluene and benzene). Using the same exposure scenario described above for soccer players, concentrations of both chemicals in the air above artificial turf soccer fields were below the Proposition 65 screening levels, suggesting a negligible risk of developmental or reproductive toxicity via the inhalation route of exposure.

From among the 20 chemicals detected at the highest levels by Dye et al. (2006), seven were also detected in the New York State (2009) study. Concentrations of these seven chemicals were from 5- to 53-fold higher in the air above indoor fields (Dye et al., 2006) compared to the air above outdoor fields (New York State, 2009). Concentrations of particulates were also higher in the indoor study. Therefore, using indoor data to calculate health risks from outdoor play overestimates the outdoor risks.

Does Artificial Turf Promote Infection of Athletes by the Bacterium Methicillin-Resistant Staphylococcus aureus (MRSA)?

MRSA Outbreaks in Sports

Staphylococcus aureus is a bacterium that can cause serious infections in humans. A strain has developed that is resistant to the antibiotic methicillin, termed methicillin-resistant *Staphylococcus aureus* (MRSA). This strain has caused a number of outbreaks in team sports including football, wrestling, rugby and soccer. Participation in contact sports increases the risk of infection by MRSA. Skin abrasions and other types of skin trauma also increase the risk of infection by MRSA. Person-to-person contact is the primary way MRSA is spread. Whether transmission occurs via inanimate objects (including playing surfaces) is less certain.

Artificial Turf and MRSA

It is not known if the new generation of artificial turf causes more MRSA infections than natural turf. However, one study of high school football demonstrated more "surface/epidermal injuries" for games played on the new generation of artificial turf compared to natural turf. Since skin trauma increases the risk of infection by MRSA, careful monitoring and treatment of such wounds may help prevent MRSA outbreaks.

It seems unlikely that the new generation of artificial turf is itself a source of MRSA, since MRSA has not been detected in any artificial turf field.

Data Gaps

- Using indoor data to estimate the health risks from outdoor fields probably overestimates those risks.
- Only two outdoor artificial turf fields were evaluated in the New York State (2009) study. The same two fields comprised the TRC (2009) study. Testing additional outdoor fields for the release of chemicals and particulate matter is warranted.
- Dye et al. (2006) did not determine what amount of each chemical was released by the artificial turf field and what amount was present in the ambient air. Therefore, future studies of artificial turf fields should include measurements from both above the fields and off of the fields.
- No study has measured the metals content of the particulates released by artificial turf fields. In addition, it is not known if field use increases particulate release.
- The variables of field age and field temperature should be monitored to determine whether they influence the release of chemicals and particulates into the air above these fields.
- Data are needed for the amount of time athletes spend on artificial turf playing fields. Data are needed for a variety of sports, age groups, and for both men and

women. Other subgroups with potentially heavy exposure to fields include coaches, referees, and maintenance workers.

- Only a single study was located that compared the rate of skin abrasions on the new generation of artificial turf to natural turf. This was for high school football. Similar studies are needed for other sports, age groups, and for both male and female athletes.
- No data were located on the seriousness of the skin abrasions suffered by athletes on the new generation of artificial turf compared to natural turf.
- The bacterium MRSA has not been detected in artificial turf fields. However, fields in California have not been tested. Therefore, fields from different regions of the state should be tested to verify that the new generation of artificial turf does not harbor MRSA or other bacteria pathogenic to humans.

Work in Progress

OEHHA is currently working to fill the above data gaps. OEHHA will sample air from above the new generation of artificial turf fields in outdoor settings and measure concentrations of potentially hazardous chemicals and particulates. Coaches will be surveyed to determine how much time athletes spend on these fields. Rates of skin abrasion will be measured on artificial and natural turf. Various components of the artificial turf, as well as soil and grass from natural turf, will be assayed for bacteria. Using these new data, OEHHA will determine whether the new generation of artificial turf playing fields releases chemicals or particulates into the air that pose an inhalation risk to persons using the fields. OEHHA will also determine whether artificial turf fields increase the risk of infection by dangerous bacteria such as MRSA.

Introduction

The California Tire Recycling Act (Public Resources Code 42870 et seq.) requires the California Integrated Waste Management Board (CIWMB) to develop new markets for recycled tires. The use of recycled tires in the new generation of artificial turf playing fields is one such new application. In the new generation of artificial turf playing fields, rubber crumb made from recycled tires serves as an artificial soil, filling in between the artificial blades of grass. This rubber infill softens the surface, helping to prevent injuries and facilitating rapid drainage. The infill is often recycled crumb rubber alone, or a combination of rubber and sand. Two other types of infill materials are new plastic granules and mulched coconut husks. The inclusion of an infill layer is one of the principal reasons the new generation of artificial turf outperforms previous generations.

The new generation of outdoor artificial turf playing fields has important advantages over natural turf. The fields can be used around the clock with little or no down time for repair, are weather resistant, and require no watering, fertilizer or pesticides. However, a number of unanswered questions remain concerning their safety for human health. Therefore, as part of their stewardship of tire recycling in California, CIWMB has contracted with the Office of Environmental Health Hazard Assessment (OEHHA) to evaluate the following two aspects:

1. Whether these fields emit chemicals or particulates into the outdoor air at levels that constitute a potential human health hazard via the inhalation route of exposure, and
2. Whether these fields increase the risk of infection by methicillin-resistant *Staphylococcus aureus* (MRSA).

This report summarizes what is available in the published literature about these two aspects, with emphasis on the crumb rubber component of the artificial turf fields. Most of the studies discussed in the report presented original data covering the volatile chemicals and particulates detected in the air above artificial turf fields, the volatile chemicals emitted by recycled rubber, and the association between skin damage and artificial turf to MRSA outbreaks in athletic teams. MRSA is of particular concern due to its identification as the causative agent in a number of infectious outbreaks in high school, college, professional and club sports (see Part II). A bibliography is also included at the end of the report listing relevant studies that were not cited in the text.

It should be noted that although one study discussed in this report did analyze the particulates in the air over these fields (Dye et al., 2006), the particulates were not analyzed for heavy metals, including lead. Therefore, there are no data with which to estimate the health risks from inhalation exposures to heavy metals emitted by these fields via airborne particulates.

After discussing the published literature, each section in this report lists conclusions and identifies data gaps. At the end of Part I, the available but limited data on chemicals and

particulates in the air above artificial turf are used to estimate the risk of cancer or developmental toxicity to soccer players using these fields. This screen only addresses the inhalation route of exposure. As mentioned above, since Dye et al. (2006) did not measure the metals content of inhalable particulates, this screen does not address the hazards posed by the inhalation of heavy metals such as lead.

OEHHA is currently performing a study to fill the data gaps identified in this report. OEHHA will sample air from above the new generation of artificial turf fields in outdoor settings and measure concentrations of potentially hazardous chemicals and particulates. Coaches will be surveyed to determine how much time athletes spend on these fields. Rates of skin abrasion will be measured on artificial and natural turf. Various components of the artificial turf, as well as soil and grass from natural turf, will be assayed for bacteria. Using these new data, OEHHA will determine whether the new generation of artificial turf playing fields releases chemicals or particulates into the air that pose an inhalation risk to persons using the fields. OEHHA will also determine whether artificial turf fields increase the risk of infection by dangerous bacteria such as MRSA.

Part I: Chemicals and Particulates in the Air above Artificial Turf

Studies that measured chemicals and particulates in the air above the new generation of artificial turf playing field

Table 1 shows five studies that measured chemicals and particulates in the air above the new generation of artificial turf playing field. For the studies by Dye et al. (2006), the Instituto De Biomecanica De Valencia (IBV, 2006), van Bruggen et al. (2007) and Milone & MacBroom (2008), the fields contained rubber crumb manufactured from recycled tires. The rubber crumb in the fields measured by Broderick (2007) was also likely recycled material, although this was not specifically stated in the reports. All fields were outdoors except those in Dye et al. (2006), which were soccer pitches in three indoor stadiums in Norway. Therefore, it is likely that the concentrations of chemicals and particulates measured by Dye et al. (2006) were higher than what would have been measured had the fields been outdoors.

Study quality and characteristics

The studies by Dye et al. (2006) and van Bruggen et al. (2007) were performed by governmental institutes located in Norway and The Netherlands, respectively. The study by IBV was performed by a university-affiliated research institute in Spain. Broderick (2007) refers to J.C. Broderick & Associates, Inc., an environmental consulting and testing firm located in New York State. Milone & MacBroom refers to an environmental consulting firm located in Connecticut.

The study by Dye et al. (2006) is the most detailed of the five, presented in a formal institute report. Multiple air samples were collected from above three indoor soccer pitches, two of which contained infill of ground rubber; however, samples from outside the stadiums were not collected, so that no conclusions can be drawn concerning the concentrations of chemicals and particulates in the vicinities of these stadiums. Thus, it is difficult to assess which chemicals were released by the artificial turf and which were already present in the ambient air. The study included data on the environmental conditions during sampling such as temperature, relative humidity and barometric pressure. Indoor ventilation rates were not measured. The chemical and particulate sampling height(s) above the pitches were not indicated. This study measured volatile organic chemicals (VOCs), polycyclic aromatic hydrocarbons (PAHs) in the gas phase and associated with particulate matter (PM_{10}), phthalates in the gas phase, and particulate matter ($PM_{2.5}$ and PM_{10}). Thirty-eight PAHs were assayed. Comparing the two fields containing infill made of ground rubber, there is generally good agreement between the chemicals and particulates detected over the two fields. For example, Table 6a in the report lists the concentrations of benzothiazole, toluene, 4-methyl-2-pentanone and total volatile organic compounds (TVOCs) measured over the two fields; the concentrations measured over the first field were within 0.7-, 5.6-, 1.0- and 2.5-fold, respectively, of the concentrations measured over the second field. For the three PAHs occurring at the highest concentrations over both fields (naphthalene, 2-methylnaphthalene, acenaphthylene), the values from the first field were within 2.7-fold of the values from

the second field. With regard to particulate matter, the concentration of PM_{10} collected from the two fields was 40.1 and 31.7 micrograms per cubic meter ($\mu g/m^3$), while $PM_{2.5}$ was 17.3 and 18.8 $\mu g/m^3$, again demonstrating good agreement between the two fields.

Dye et al. (2006) also measured the air above a field containing infill made of "thermoplastic elastomer." Comparing this field to the other two fields containing recycled rubber infill, the air above the field containing thermoplastic elastomer contained lower levels of VOCs, PAHs (both in the gas phase and associated with particulates), total $PM_{2.5}$ and the $PM_{2.5}$ fraction consisting of rubber dust.

van Bruggen et al. (2007), also presented in a formal institute report, collected multiple samples from above four outdoor soccer fields made of artificial turf, as well as samples upwind of the fields to measure the ambient environmental levels. Weather data included wind speeds, and the heights above the fields where sampling was performed were also reported. This study only measured nitrosamines. Eight were assayed.

The short report from Broderick (2007) shows that while duplicate samples were collected from above two outdoor artificial turf fields, as well as off of the fields, no weather data (including wind speed) were presented. In addition, the reports do not indicate the height above the fields at which sampling was performed. This study only measured PAHs (in the gas phase and in particulates collected on a 2.0 μm filter). Sixteen PAHs were assayed.

The IBV (2006) study was in the form of a meeting presentation, available online at the Web site for the 2006 Dresden Conference entitled, "Impact of Sports Surfaces on Environment and Health." Six samples were collected over a single outdoor artificial soccer pitch. No background air samples were collected from off the pitch. Thus, it is difficult to assess which chemicals were released by the artificial turf and which were already present in the ambient air. No weather data were reported, and few other methodological details were provided. This study measured VOCs, PAHs (whether in gas or particulate phase was not indicated), and hydrogen sulfide.

The most recent study (Milone & MacBroom, 2008) collected a single air sample from above each of two artificial turf fields in Connecticut. Four additional samples were collected from off of each field. Temperature, humidity and wind speed/direction data were included, and a sampling height of 4 feet above the surface was utilized. Analysis was for seven nitrosamines, 4-(tert-octyl)phenol and benzothiazole. These last two chemicals had been detected volatilizing from recycled rubber crumb analyzed under laboratory conditions (see study by Environment & Human Health, Inc. (EHHI, 2007) in Table 4).

Comparing studies

Dye et al. (2006) identified 94 chemicals in the air above artificial turf fields located in indoor stadiums. Over 200 additional VOCs were detected in this study (13 to 16 percent by weight), but not identified. By comparison, the IBV (2006) study detected 13

Table 1. Air measurements above artificial turf fields

Reference	Scenario	Chemicals/particulates measured
Dye et al., 2006	Three indoor soccer stadiums 10-18°C 42-53% humidity One field 2 months old (other 2 ages not indicated) Two fields contained recycled rubber crumb (yielding values shown on right)	VOCs : 69 detected at $\geq$ 0.8 µg/m^3 PAHs: 22 detected at $\geq$ 1.0 ng/m^3 (mostly in the gas phase, some in the particulate fraction) Phthalates: 3 detected at $\geq$ 0.06 µg/m^3 (in the gas phase) $PM_{2.5}$: total = 18.8 µg/m^3, rubber = 8.8 µg/m^3 PM_{10}: total = 40.1 µg/m^3, rubber = 9.3 µg/m^3 Twenty highest VOCs were (in µg/m^3): toluene (85), butenylbenzene (82.5), benzoic acid (81), diethenylbenzene (41), benzothiazole (31.7), p- and m-xylene (25.5), ethylbenzaldehyde (19.7), acetonitrile (16.8), acetone (15.3), o-xylene (13.1), 4-methyl-2-pentanone (12.7), alpha pinene (10.5), 3-phenyl-2-propenal (10.2), cyclohexanone (9.8), pentenyl benzene (7.3), pentanedioic acid dimethylester (6.8), ethylbenzene (6.7), formaldehyde (6.5), hexenylbenzene (6.1), styrene (6.1) Ten highest PAHs (total in gas phase plus PM_{10}-associated) were (in ng/m^3): naphthalene (2700 or 56 for two different methods), acenaphthylene (78.1), 2-methylnaphthalene (57.8), 1-methylnaphthalene (42.6), biphenyl (32.8), phenanthrene (25), fluorene (19.2), dibenzofurane (17), acenaphthene (14.2), pyrene (4.4) Three phthalates were (in µg/m^3): dibutylphthalate (DBP, 0.38), diisobutylphthalate (DiBP, 0.13), diethylphthalate (DEP, 0.06)
IBV 2006	One outdoor soccer field	VOCs: 5 detected (highest value in µg/m^3): p- and m-xylene (4.4), toluene (3.1), o-

Reference	Scenario	Chemicals/particulates measured
	containing recycled rubber crumb	xylene (2.5), ethylbenzene (2.2), benzene (0.4) PAHs: 8 detected (highest value in ng/m^3): phenanthrene (6.9), pyrene (4.2), fluoranthene (1.1), fluorene (0.92), anthracene (0.46), acenaphthene (0.32), naphthalene (0.3), acenaphthylene (0.21)
Broderick 2007	Two outdoor high school athletic fields containing rubber crumb	All 16 PAHs assayed were below the minimum detection level of 6.0 µg/m^3
van Bruggen et al., 2007	Three outdoor fields containing recycled rubber crumb and one containing new rubber For fields with recycled rubber, one recently installed and two older than one year Sampling performed between 11-20°C on sunny days at 30-100 cm above pitch	All eight nitrosamines assayed were below the minimum detection limit of 8-16 ng/m^3
Milone & MacBroom 2008	Two outdoor fields containing recycled rubber crumb Sampling performed on	Seven nitrosamines were assayed: samples from both fields were below the minimum reporting limit of 1.0 to 1.4 µg/m^3 4-(tert-octyl)phenol: samples from both fields were below the minimum reporting

Reference	Scenario	Chemicals/particulates measured
	summer days between 75 and 85°F with light winds Samples taken at 4 feet above surface	limit of 0.19 to 0.21 μg/m^3 Benzothiazole: one field's sample was below the minimum reporting limit of 0.19 to 0.21 μg/m^3; the other field's sample was 1.0 μg/m^3 (includes correction for 39% sample spike recovery)

chemicals and Milone & MacBroom (2008) detected one. The two remaining studies utilized detection levels that were too high; as a consequence, no chemicals were detected.

The failure to detect PAHs in the study by Broderick (2007) is consistent with the data in Dye et al. (2006). The individual PAH levels in Dye et al. (2006) were all $\leq$ 2.7 $\mu g/m^3$, while the individual PAH detection levels in Broderick (2007) were 6.0 $\mu g/m^3$. Utilizing nitrosamine detection levels of 8-16 ng/m^3, van Bruggen et al. (2007) did not detect nitrosamines above three outdoor fields containing recycled rubber. Some nitrosamines volatilize readily from soil and water surfaces, while others are considered nonvolatile. Their study was initiated after a single air measurement above an artificial turf field containing recycled rubber detected N-nitrosodimethylamine (NDEA) at 93 ng/m^3. Similarly, Milone & MacBroom (2008) did not detect nitrosamines above two fields (reporting limits 1.0 to 1.4 $\mu g/m^3$). Dye et al. (2006) also did not report any nitrosamines above two indoor fields containing recycled rubber, although the nitrosamine detection levels were not indicated in the report.

Table 2 shows a comparison of the concentrations of the eight PAHs and five VOCs detected by IBV (2006) to the highest values reported by Dye et al. (2006). Despite uncontrolled variables such as field age and temperature during sampling, all 13 chemicals detected by IBV (2006) were detected by Dye et al. (2006). For 12 of the 13, the concentrations were lower in IBV (2006). This might be expected, since the field in the IBV (2006) study was outdoors, while the fields in the Dye et al. (2006) study were indoors. For the eight PAHs, concentrations measured in IBV (2006) ranged from similar (pyrene) to 9000-fold (naphthalene) lower than the corresponding concentration measured in Dye et al. (2006). For the five VOCs the differences were less, ranging from 3-fold (ethylbenzene) to 27-fold (toluene) lower in the IBV (2006) study. The VOC benzothiazole was also detected over an outdoor field by Milone & MacBroom (2008); its concentration was 32-fold lower over this outdoor field compared to the concentration reported over indoor fields by Dye et al. (2006). Therefore, the data in IBV (2006) and in Milone & MacBroom (2008) support those of Dye et al. (2006) in that all 13 chemicals detected over outdoor fields were detected at higher levels over indoor fields. This suggests that persons using the new generation of artificial turf in outdoor settings are exposed to many of the same chemicals as persons exposed indoors, albeit at lower concentrations. Thus, exposure calculations for outdoor play based on the data from Dye et al. (2006) would probably overestimate exposure to most chemicals. Since neither the IBV (2006) study nor the Dye et al. (2006) study measured the background level of chemicals, it remains possible that the 13 chemicals discussed above were not emitted from the artificial turf, but were already present in the ambient air. However, due to the presence of a number of VOCs that Dye et al. (2006) considered to be typical rubber components (such as benzothiazole, 4-methyl-2-pentanone and styrene), the authors believed that the rubber infill was the source of many of the VOCs they detected.

Unfortunately, since the report of Dye et al. (2006) contained the only published values for $PM_{2.5}$ and PM_{10} from above artificial turf fields, there are no other studies for comparison. As discussed above, the good agreement between the PM values from the

two fields measured in the study by Dye et al. (2006) provide some assurance that the data are reliable. However, it is difficult to use these indoor data from Dye et al. (2006) to predict the concentrations of PM over outdoor artificial turf fields.

Table 2. Comparison of chemical concentrations measured in the studies of Dye et al. (2006) and IBV (2006)

Chemical	**Concentration in IBV (2006) (μg/m^3)**	**Concentration in Dye et al. (2006) (μg/m^3)[1]**	**[Dye]/[IBV]**
PAHs			
Acenaphthene	0.00032	0.014	44
Acenaphthylene	0.00021	0.078	371
Anthracene	0.00046	0.002	4.3
Fluoranthene	0.0011	0.004	3.6
Fluorene	0.00092	0.019	21
Naphthalene	0.0003	2.7 or 0.056	9000 or 187
Phenanthrene	0.0069	0.025	3.6
Pyrene	0.0042	0.004	1
VOCs			
Benzene	0.4	2.4	6
Ethylbenzene	2.2	6.7	3
Toluene	3.1	85	27
o-Xylene	2.5	13.1	5.2
p and m-Xylene	4.4	25.5	5.8

[1]Highest value reported

Conclusions

- Only five studies were located which quantified the chemicals and particles in the air above the new generation of artificial turf playing fields.
- The study by Dye et al. (2006) of indoor soccer stadiums provides the largest dataset: 69 VOCs at $\geq$ 0.8 μg/m^3, 22 PAHs at $\geq$ 1.0 ng/m^3 (mostly in the gas phase), 3 phthalates at $\geq$ 0.06 μg/m^3 (in the gas phase), $PM_{2.5}$ at 18.8 μg/m^3 and PM_{10} at 40.1 μg/m^3 were detected.
- The chemicals identified by Dye et al. (2006), as well as their concentrations, are consistent with the other four studies.

Data Gaps

- A study similar to that of Dye et al. (2006), that assays a large range of VOCs and particulates over multiple fields, is needed for outdoor artificial turf fields, since use of the Dye et al. (2006) data for estimating the health risks from outdoor fields probably overestimates those risks.
- Dye et al. (2006) did not sample air from outside the stadiums for comparison to the indoor samples. Therefore, it is not possible to know what amount of each

chemical was contributed by the artificial turf field and what amount was present in the ambient air.

- Approximately 200 of the 300 VOCs (13 to 16 percent by weight) detected by Dye et al. (2006) were not identified, but were only reported as peaks on a graph. Therefore, potential health risks posed by these chemicals cannot be estimated.
- Many of the chemicals identified in the study of Dye et al. (2006) have no associated health-based screening levels, so that their health risks cannot be estimated. Thus, any attempt to classify these chemicals as carcinogens or developmental/reproductive toxicants will be an underestimate.
- The Dye et al. (2006) study provides the only data on particulate levels from above artificial turf playing fields. Data from above outdoor fields are needed, where the values are likely to be lower.
- Dye et al. (2006) did not measure the metals content of the airborne particulate matter ($PM_{2.5}$ and PM_{10}). Thus, the health risks posed by inhaled particulates and the metals they contain, such as lead, cannot be determined.
- The effect of temperature on chemical and particulate levels has not been measured.
- The contribution of field age to chemical and particulate levels has not been measured.
- The effect of field use on the levels of either VOCs or particulates has not been measured. Thus, it is possible that air sampling before or during games would give different results.

Studies that measured chemicals emitted by rubber flooring made from recycled tires

CIWMB sponsored two studies (2003 and 2006) that measured chemical emissions from tire-derived rubber flooring. This type of flooring is used in indoor applications such as auditoriums and classrooms. The flooring contained at least 80 percent tire-derived rubber, making it chemically very similar to the crumb rubber infill used in many new generation artificial turf fields, including those in the study of Dye et al. (2006) and the other studies in Table 1. Emissions of individual chemicals were measured in environmental chambers and normalized to the surface area of flooring in each chamber, yielding chemical-specific emission factors. The data cannot be directly compared to the air concentrations from Dye et al. (2006). However, the emission factors were used to model the chemical concentrations expected to occur in a variety of indoor settings. Table 3 shows those concentrations for the largest rooms modeled: an auditorium and a classroom. The results for the largest rooms are presented since these are closest to the dimensions of the indoor stadiums in the Dye et al. (2006) study.

Table 3. Indoor emissions from tire-derived rubber flooring

Reference	Indoor area modeled	Modeled room chemical concentrations (μg/m^3) based on measured emission factors
CIWMB, 2003	State auditorium, 70x70x15 ft, 73,500 ft^3 3.5 air changes per hour Flooring samples tested contained at least 80% recycled styrene butadiene rubber and ethylene propylene diene monomer Chemical emission rates were determined at 14 days, modeled concentrations in right column are based on the highest measured emission rate for each chemical	VOCs 21 identified: α, α-dimethylbenzenemethanol (420), acetophenone (160), diethyl propanedioate (80), propylene glycol (47), 1-ethyl-3-methylbenzene (43), 1,2,4-trimethylbenzene (40), α-methyl-styrene (38), benzothiazole (37), 1-ethyl-4-methylbenzene (22), 1,2,3-trimethylbenzene (18), triethylphosphate (18), 1-ethyl-2-methylbenzene (13), 2-ethylhexyl acetate (11), cumene (5.5), 2-ethyl hexanoic acid (3.9), 1-methyl-2-pyrrolidinone (1.8), dodecane (1.4), naphthalene (0.99), nonanal (0.74), decanal (0.5), ethyl benzene (0.5)
CIWMB, 2006	State classroom, 960 ft^2 x8.5 ft high, 8160 ft^3 0.9 air changes per hour Most flooring samples contained $\geq$ 81% tire-derived rubber Chemical emission rates were determined at 14 days, modeled concentrations in right column are based on the highest measured emission rate for each chemical	VOCs 31 identified: benzothiazole (1677), methyl isobutyl ketone (154), m-/p- xylene (142), carbon disulfide (116), acetophenone (86), cyclohexanone (77), toluene (60), acetone (43), ethyl benzene (32), benzene (24), chlorobenzene (23), nonanal (22), n-undecane (21), octanal (18), styrene (17), acetaldehyde (16), butyraldehyde (14), α-methylstyrene (12), phenol (10), decanal (9), isopropyl alcohol (9), 1,2,4-trimethylbenzene (9), formaldehyde (7), n-decane (6), 1-ethyl-4-methylbenzene (6), 1,3,5-trimethylbenzene (6), naphthalene (4), hexanal (3), 4-phenylcyclohexene (3), 1,2,3-trimethylbenzene, o-xylene (2)

In the 2003 CIWMB study, eight of 21 chemicals emitted by the tire-derived flooring were also detected above artificial turf fields in indoor stadiums (Dye et al., 2006). Half of these (4/8) were modeled as occurring at higher concentrations in the auditorium compared to the stadiums. In the 2006 CIWMB study, 18 of 31 chemicals emitted by the flooring were also detected above artificial turf fields in indoor stadiums (Dye et al., 2006), with 16 of the18 occurring at higher concentrations in the modeled state classroom compared to the indoor stadiums. For those chemicals detected in CIWMB (2003) or (2006) but not in Dye et al. (2006), it is not known if they were even assayed in the latter study. There were six chemicals detected in both CIWMB studies and by Dye et al. (2006): 1,2,4-trimethylbenzene, 1-ethyl-4-methylbenzene, benzothiazole, ethylbenzene, naphthalene and nonanal. Three of these were emitted by 100 percent rubber crumb heated under laboratory conditions: 1,2,4-trimethylbenzene, benzothiazole and ethylbenzene (see Table 4). This suggests that these three chemicals in the air are reliable markers for the crumb rubber from recycled tires used as infill in artificial turf. Ethylbenzene and naphthalene were also detected by IBV (2006) and benzothiazole was detected by Milone & MacBroom (2008) in outdoor air above artificial turf fields (Table 1), while all except 1-ethyl-4-methylbenzene were emitted by sections of artificial turf maintained in environmental chambers (see next section, Moretto, 2007).

It should be mentioned that recycled tire rubber used as indoor flooring (CIWMB 2003) emitted hundreds of low-level VOCs that were not identified. Hundreds of low-level VOCs were also detected in the air over artificial turf in indoor stadiums (Dye et al., 2006). When all VOCs were totaled (TVOCs), they reached up to 716 $\mu g/m^3$ in the Dye et al. study (2006) and exceeded one milligram (mg)/m^3 in the CIWMB study (2003). The health effects from breathing low levels of many volatile organic chemicals have not been adequately studied. This lack of information should be noted when calculating the health risks from individual chemicals that were identified in these studies.

Conclusions

- Twenty of the VOCs released by tire-derived indoor rubber flooring (CIWMB 2003 and 2006) were also detected in the air above indoor soccer pitches made of the new generation of artificial turf containing rubber infill.
- For the more recent flooring study (CIWMB, 2006), 18 of 31 chemicals emitted by the flooring were also detected in the air above the turf (Dye et al., 2006). This demonstrates good agreement between the studies and supports using the data from Dye et al. (2006) for making health risk estimates via inhalation.
- Three VOCs were consistent markers for tire-derived rubber: 1,2,4-trimethylbenzene, benzothiazole and ethylbenzene.

Data Gaps

- Tire-derived flooring emitted hundreds of low-level VOCs that were not identified, while other identified chemicals had no associated health-based

screening levels. Therefore, the health risks posed by these chemicals cannot be estimated.

- Total VOCs (TVOCs) emitted by tire-derived flooring exceeded one mg/m^3. Similar measurements of TVOCs should be made above artificial turf fields, since breathing low levels of a mixture of many VOCs may pose a health risk.

Laboratory studies of the emission of volatile chemicals from tire-derived crumb rubber infill

Three studies were located which analyzed the gaseous emissions from tire-derived crumb rubber infill in laboratory settings (Table 4). The studies by Plesser and Lund (2004) and EHHI (2007) analyzed samples of 100 percent rubber infill heated to 60-70°C, while Moretto (2007) used whole sections of artificial turf (containing recycled crumb rubber infill) maintained at 23°C in environmental chambers.

Moretto (2007) identified 112 VOCs emitted from the artificial turf. This is more than reported in any other study. Twenty-seven of these were also detected by Dye et al. (2006) over artificial turf fields in indoor soccer stadiums. Moretto (2007) did not provide quantitative data on the amounts of chemicals that were released by the sections of artificial turf. Of the 12 VOCs identified by Plesser and Lund (2004), five were also detected by Dye et al. (2006). From among the four VOCs identified in EHHI (2007), only benzothiazole was also identified by Dye et al. (2006).

Conclusions

- The study by Moretto (2007) of artificial turf in environmental chambers confirmed 27 of the chemicals detected in indoor soccer stadium air by Dye et al. (2006). This supports the use of the data from Dye et al. (2006) for estimating the health risks posed by artificial turf playing fields.
- Benzothiazole was detected in two of three emissions studies in Table 4 (EHHI, 2007; Moretto, 2007), in both indoor flooring studies in Table 3 (CIWMB 2003 and 2008), and in air above artificial turf fields (Table 1; Dye et al., 2006; Milone & MacBroom, 2008). It appears to be a consistent and relatively high-level off-gassing product of rubber crumb made from recycled tires.

Data Gaps

- Many of the chemicals identified in the chamber emission study of Moretto (2007) were not detected in stadium air by Dye et al. (2006). This may be due to the conditions used by Moretto (2007): a sealed environmental chamber, maintained at 23°C, in which chemicals emitted at low levels have a chance to accumulate. Since chemical concentrations in the chambers were not provided in the report, this cannot be determined.

Table 4. Gaseous emissions per gram of tire-derived rubber in laboratory studies

Reference	Conditions	VOCs detected (in ng/g of rubber)
Plesser and Lund, 2004	Samples heated at 70°C for 30 minutes	Twelve VOCs detected: 1,2,4-trimethylbenzene (102), toluene (80), m/p-xylene (37), o-xylene (35), cis-1,2-dichloroethene (32), n-butylbenzene (31), p-isopropyltoluene (23), 1,3,5-trimethylbenzene (23), ethylbenzene (18), propylbenzene (15), iso-propylbenzene (12), trichloromethane (8)
EHHI, 2007	Samples heated at 60°C for 42 minutes	Four VOCs detected: benzothiazole (867), butylated hydroxyanisole or BHT alteration product (53), 4-(tert-octyl)-phenol (22), hexadecane (1.58)
Moretto, 2007	Samples off-gassed for 28 days in chambers at 23°C	112 VOCs detected, but emissions per gram of rubber not indicated

Chemicals and particulates emitted during rubber manufacturing

Due to the large numbers of chemicals and materials used to manufacture rubber, many occupational health studies have examined the safety of various steps in the manufacturing process. The studies listed in Table 5 measured the concentrations of volatile chemicals and particulates to which rubber workers have been exposed. While it is to be expected that the levels of these chemicals would be higher in factory air during the rubber manufacturing process compared to a setting where the rubber end product is used, such as in artificial turf infill, some of the more prevalent chemicals should be detected in both situations. Such a comparison can be a useful test of the validity of the studies presented in Table 1 that attempted to identify the chemicals and particulates above artificial turf fields containing recycled tire rubber as infill.

With respect to VOCs, Rappaport and Fraser (1977) measured six VOCs in a vulcanization area of a tire manufacturing plant. Three of these, toluene, ethylbenzene and styrene, were also detected by Dye et al. (2006) in indoor stadium air above new generation artificial turf containing recycled crumb rubber infill; the stadium concentrations were 51-fold, 73-fold and 78-fold lower than the factory concentrations, respectively. Cocheo et al. (1983) measured VOCs in the vulcanization and extrusion areas of a tire retreading factory. From among the 60 VOCs they identified, 15 were also detected by Dye et al. (2006) in the indoor stadium study; concentrations of the 15 VOCs were from 4-fold to 625-fold lower in the artificial turf application. Van Ert et al. (1980) investigated eight organic solvents used in a tire and tube manufacturing plant. Measurements were performed in the tire building and final inspection areas. Five of the eight solvents were also detected by Dye et al. (2006): heptane, toluene, octane, benzene and xylene. The concentrations ranged from 34-fold to 10,750-fold lower in the indoor stadium air compared to the factory air. Armstrong et al. (2001) identified five VOCs in rubber tire manufacturing plants. Of these, three (formaldehyde, benzene and toluene) were also identified by Dye et al. (2006), but at 34-fold to 238-fold lower concentrations. Lastly, two of four VOCs identified by Correa et al. (2004) in the outdoor air circulation area of a tire recapping unit were also identified by Dye et al. (2006); toluene and styrene were 131-fold and 7-fold lower in the air above indoor artificial turf fields compared to the tire recapping area. Thus, five separate studies of rubber manufacturing have detected VOCs that were also in the air over the new generation of artificial turf fields; in each case the chemical was at a lower concentration above the fields compared to the manufacturing setting. These findings support the use of the data from Dye et al. (2006) for estimating chemical exposures to persons using the new generation of artificial turf fields, at least until similar measurements can be performed in outdoor settings.

Nitrosamines have been detected by sampling air in rubber manufacturing plants (Table 5). Oury et al. (1997) measured total nitrosamines in tire factory air. The highest concentration detected was 2.3 $\mu g/m^3$. Monarca et al. (2001) detected two nitrosamines (N-nitrosodimethylamine [NDMA] and N-nitrosomorpholine [NMOR]) in the range of 1-2 $\mu g/m^3$ inside a styrene-butadiene rubber factory. Iavicoli and Carelli (2006) sampled air in a rubber manufacturing plant. While the great majority of air samples had no

Table 5. Chemicals and particulates released into the air during rubber manufacturing

Reference	Work area sampled	Chemicals and particulates measured
Nutt, 1976	Tire factory areas including mixing, extrusion, curing, pressing, trimming	Benzo[a]pyrene was Soxhlet-extracted from particulates: mean concentration of 49 factory air samples (12.3 ng/m^3) was not significantly different from outside air B[a]P concentration
Rappaport and Fraser, 1976	Rubber vulcanization performed in the lab	Fourteen VOCs were identified, with the highest relative concentrations being methylbenzene, 4-vinylcyclohexene, styrene, tert-butylisothiocyanate, and 1,5,9-cyclododecatriene
Rappaport and Fraser, 1977	Tire vulcanization area in a factory	Six VOCs measured (mean values in µg/m^3): toluene (4,371), ethylbenzene (486), styrene (473), 4-vinylcyclohexene (408), 1,5,9-cyclododecatriene (105), 1,5-cyclooctadiene (28.5)
Van Ert et al., 1980	Tire building and final inspection areas in two tire and tube manufacturing plants	Eight organic solvents measured (highest mean values in mg/m^3): hexane (64), heptane (8.6), isopropanol (7.9), toluene (3.2), pentane (2.2), octane (1.9), benzene (1.3), xylene (1.3)
Cocheo et al., 1983	Vulcanization and extrusion areas in a tire retreading factory	Sixty VOCs measured, the following being the ten highest in concentration (mg/m^3): diisobutyl phthalate (2.5), cyclohexene-1-methyl-4-(1-methylvinyl) (1.7), benzene (1.2), toluene (0.8), methylcyclohexane (0.8), dibutyl phthalate (0.5), heptane (0.5), 1-isopropyl-4-methylbenzene (0.45), 2,6-di-ter-butyl-4-ethylphenol (0.42), cyclododecatriene (0.4)
Heitbrink and McKinnery, 1986	Tire manufacturing plants: mixing and milling areas	Mean total aerosol ranges (in mg/m^3): for mixing (0.08 to 1.54), for milling (0.2 to 1.22); mean respirable aerosol ranges (in mg/m^3): for mixing (0.06 to 0.34), for milling (0.08 to 0.4)
Oury et al., 1997	Tire factory including steps of mixing, pressing, quality control and storage	Total nitrosamines (NDMA, NDEA, NDBA, NPIP, NMOR) were between 0.01 and 2.3 µg/m^3 (range of 45 measurements)
Meijer et al., 1998	Rubber manufacturing areas in belt factory (compounding and mixing, calendaring, extruding, repair, curing)	"Inhalable dust" mean values ranged from 0.9 to 9.4 mg/m^3
Fracasso et al., 1999	Rubber manufacturing areas included weighing, mixing, calendaring, compounding,	PAH concentration ranges (in µg/m^3): phenanthrene (not detected), pyrene (0.006 to 0.213), benzo(a)anthracene (not detected to 0.005), chrysene (0.01 to 0.05), benzo(a)pyrene (not detected to 0.012), dibenzo(a,h)anthracene (0.003 to 0.106)

Reference	Work area sampled	Chemicals and particulates measured
	extruding	
Armstrong et al., 2001	Five rubber tire manufacturing plants	Aerosol particle concentrations (means in μg/m^3): PM_1 [<1 μm] (120); PM_1 to PM_5 [1 to 5 μm] (123); PM_5 to PM_{10} [5 to 10 μm] (109); VOCs (means in mg/m^3) formaldehyde (0.22), benzene (0.57), furfural (< 0.91), isopropyl alcohol (5.66), toluene (12.38)
Monarca et al., 2001	Styrene-butadiene rubber factory	Total mean PM_{10}=0.23 mg/m^3; mean nitrosamines (in μg/m^3): NDMA (0.98), NMOR (2.28); 17 PAHs were Soxhlet-extracted from PM_{10}, with the 10 highest (in ng/m^3): dimethylnaphthalene (1200), naphthalene (400), pyrene (29), benzo(ghi)perylene (20), indeno(1,2,3-cd)pyrene (18), phenanthrene (12), benzo(b)fluoranthene (7.3), fluoranthene (7.0), benzo(a)pyrene (5.7), benzo(a)anthracene (2.3)
Ward et al., 2001	Rubber manufacturing plant: high exposure areas (reactor, recovery, tank farm, lab); low exposure areas (blending, baling, packaging, coagulation, water plant)	1,3-butadiene concentrations, mean 12 hour time weighted averages (in mg/m^3) for: high exposure areas = 3.8, for low exposure areas = 0.15
Chien et al., 2003	Two tire shredding plants-chopping, shredding, granulating and storage areas	PM_{10}, means ranged from 0.23 to 1.25 mg/m^3
Correa et al., 2004	Outdoor circulation area of a tire-recapping unit	In μg/m^3 : toluene (11,100), styrene (44.3), 4-chlorotoluene (7.6), 4-chlorostyrene (9.0), benzo(a)anthracene (16.7 extracted from particulates), chrysene (17.5 extracted from particulates)
de Vocht et al., 2006	Tire factory: milling and mixing/curing departments	"Inhalable particulate matter" mean value was 0.3 mg/m^3
Iavicoli and Carelli, 2006	Rubber manufacturing (e.g., belts, no tires)	Great majority of nitrosamine samples were below the limit of detection (0.06 μg/m^3); however, some values were higher (in μg/m^3): N-nitrosodimethylamine (0.35 for one sample), N-nitrosomorpholine (0.16, mean of 4 samples), N-nitrosodiethylamine (0.15, mean of 5 samples), N-nitrosodi-n-butylamine (0.06 for one sample)
de Vocht et al., 2008a	Polish rubber tire plant;	Geometric mean concentrations for the different departments ranged from: 1.7 to

Reference	Work area sampled	Chemicals and particulates measured
	departments sampled included crude materials, milling and mixing, pre-treating, assembly, curing, finishing, storage	5.8 mg/m^3 for inhalable aerosols, <1.0 to 578 μg/m^3 for aromatic amines
de Vocht et al., 2008b	Rubber manufacturing in five European countries	Inhalable dust measured with personal samplers on workers, means ranged from 0.72 to 1.97 mg/m^3

detectable nitrosamines (detection limit = 0.06 μg/m^3), some had detectable levels, the highest being 0.35 μg/m^3 for N-nitrosodimethylamine. All the above nitrosamine concentrations are above the minimum detection level of 8-16 ng/m^3 used by van Bruggen et al. (2007) to analyze air samples from above outdoor artificial turf fields containing recycled rubber crumb (Table 1). There are at least two possible reasons for the failure of van Bruggen et al. (2007) to detect the volatile nitrosamines, given that they were present at detectable levels during manufacturing. First, most of the more volatile nitrosamines may have been emitted by the rubber crumb prior to field installation. Second, volatilization may be so rapid that the chemicals rapidly dissipate into the atmosphere.

PAHs have also been detected in the air of factories producing rubber (Table 5). Surveying the levels in factory air, all were well below the detection level of 6.0 μg/m^3 used by Broderick (2007) when sampling the air above outdoor artificial turf fields containing recycled rubber crumb (Table 1). Thus, it is not surprising that Broderick (2007) failed to detect PAHs. Using lower detection levels, Dye et al. (2006) reported 22 PAHs at $\geq$ 1.0 ng/m^3 in the air above artificial turf fields in indoor stadiums (Table 1). Comparing the PAHs detected by Dye et al. (2006) to those reported in the occupational studies in Table 5 yields the following: two of six PAHs detected by Fracasso et al. (1999), ten of 16 detected by Monarca et al. (2001), and none of two detected by Coorea et al. (2004) were also identified by Dye et al. (2006). The agreement between Monarca et al. (2001) and Dye et al. (2006) seems close; however, while six of the PAHs were at higher levels in factory air compared to the indoor stadium air, four were at higher levels in the stadium air. A possible explanation is that Dye et al. (2006) analyzed PAHs occurring in both the gas and particulate phases, while Monarca et al. (2001) only assayed the particulate phase. Thus, the more volatile PAHs might be expected at higher levels in the former case. The four PAHs detected at higher levels by Dye et al. (2006) were in fact the relatively volatile PAHs acenaphthylene, fluorene, phenanthrene and anthracene.

Values for respirable particulate (PM_{10}; particles capable of penetrating deeply into the lungs, into the region where gas exchange occurs) concentrations in factory air were distributed over a fairly narrow range: up to 400 μg/m^3 in a tire manufacturing plant (Heitbrink and McKinnery, 1986), up to 352 μg/m^3 in five tire manufacturing plants (Armstrong et al., 2001), and up to 1250 μg/m^3 in two tire shredding plants (Chien et al., 2003). The PM_{10} concentrations were roughly ten-fold lower in the indoor stadium air measured by Dye et al. (2006), ranging up to 40.1 μg/m^3, of which 9.3 μg/m^3 was identified as rubber particulate. Inhalable particulate (relatively large particles, capable of being inhaled but not penetrating deeply into the lungs) concentrations in factory air were generally higher than respirable concentrations, ranging as high as 5800 and 9400 μg/m^3 in the studies by de Vocht et al. (2008) and Meijer et al. (1998). These results for respirable particulates are similar to those for VOCs, in that concentrations above indoor artificial turf fields were much lower than those in the factories, including the tire shredding plant (Chien et al., 2003).

Conclusions

- A number of VOCs detected above third generation artificial turf fields by Dye et al. (2006) were also detected in the air of rubber manufacturing plants. In all cases, the concentrations were lower in the air over the artificial turf fields compared to the factory settings.
- For the nitrosamines, their levels in air above artificial turf fields and in rubber factory air suggest that either these chemicals volatilize from the rubber crumb prior to installation in a field, or their levels over a field are too low to detect.
- Air sampling data from rubber factories confirm most of the PAHs detected by Dye et al. (2006) in the air over artificial turf fields.
- Air sampling in rubber factories and tire shredding plants detected levels of respirable particulates (PM_{10}) that were approximately ten-fold higher than the levels measured above third generation artificial turf fields containing rubber crumb infill (Dye et al., 2006).

Data Gaps

- Measure the time dependence (as the fields age) of respirable particulate ($PM_{2.5}$ and PM_{10}) release from artificial turf fields containing rubber crumb.
- Determine if levels of respirable particulates ($PM_{2.5}$ and PM_{10}) vary with field use; i.e., are the levels in the air higher during games compared to periods when the fields are idle?

Estimating the risk of cancer and developmental/reproductive toxicity via inhaled air in soccer players on the new generation of artificial turf.

The purpose of this section is to estimate the increased lifetime cancer risk and increased risk of developmental/reproductive toxicity due to the inhalation of volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs) by soccer players using the new generation of artificial turf playing fields. To perform this screen, the chemicals detected above artificial turf fields were compared to the California Proposition 65 list of chemicals known to the state to cause cancer or developmental/reproductive toxicity.

As described earlier in this report, Dye et al. (2006) published a study analyzing the air above three artificial turf playing fields located indoors in Norwegian soccer stadiums. This section uses these values, along with published values for age-specific breathing rates, and estimated lifetime play scenarios for soccer players on artificial turf, to calculate the following for those chemicals that also appear on the California Proposition 65 list:

1. daily chemical intake rates averaged over a lifetime to estimate the increased lifetime cancer risk, and

2. daily chemical intake rates not averaged over a lifetime, for comparison to maximum allowable dose levels (MADLs) to estimate the increased risk of developmental/reproductive toxicity.

Estimating the daily intake of air above artificial turf playing fields

Table 6 estimates the daily intake of air by soccer players from above artificial turf playing fields. The breathing rates are recommended for persons in the indicated age group engaged in "heavy" activities over "short-term" intervals. The 1.5 and 2.0 hour intervals seem to us to be reasonable estimates for the time a soccer player spends playing a timed game or practicing.

Table 6. Intake of field air on days of artificial turf field use.

Age interval	**Breathing rate[1]**	**Time of field use per day (soccer game or practice session)[2]**	**Total intake of field air per day of field use[3]**
5-15 years	1.9 m^3/hr	1.5 hr/day	2.85 m^3/day
16-18 years	1.9 m^3/hr	2 hr/day	3.8 m^3/day
19-55 years	3.2 m^3/hr	2 hr/day	6.4 m^3/day

[1] For 5-18 years: recommended mean value for short-term exposures to a child $\leq$ 18 years and performing heavy activities (US EPA Child-Specific Exposure Factors Handbook, September 2002, Table 7-14); for 19-55 years: recommended mean value for short-term exposures to adults performing heavy activities (OEHHA Technical Support Document for Exposure Assessment and Stochastic Analysis, September 2000, Table 3.9).
[2] Estimates based on length of timed game or practice session for ages < 16 years (1.5 hours) or $\geq$ 16 years (2 hours).
[3] Calculated by multiplying the value in column two by the value in column three.

Estimating the daily intake of air from above artificial turf playing fields averaged over a 70 year lifetime

The play scenarios shown in Table 7 are our best estimates for a lifetime of soccer play by a soccer enthusiast. The scenarios are not based on data. The daily intakes of air from above artificial turf fields were averaged over a 70-year lifetime, including 51 years of organized soccer play (from age 5 to 55). The daily intakes were also averaged over an entire year, since it was estimated that at most, 102 days per year (for the 19 to 22 year-old age group) would include use of artificial turf (Table 7). We consider this lifetime exposure rate of 0.464 m^3/day (Table 7) a heaviest use scenario for soccer players, since this assumes all organized soccer games and practices over a lifetime would be on artificial turf.

Table 7. Intake of field air for 51 years of artificial turf field use (soccer) averaged over a 70-year lifetime.

[1]Age inter-val	[2]Soccer play scenario on artificial turf fields	[3]Field air intake per day of field use (practice or game) for this play scenario	[4]Days of use per year for this play scenario	[5]Years of use per 70 year lifetime for this play scenario	[6]Daily field air intake for this play scenario averaged over a 70 year lifetime	[7]Daily field air intake normalized to body weight in m^3/kg-d
5-15	Two 15-game club seasons/year with 30 associated practice days	2.85 m^3/day	60 day/365 days	11 years/70 years	0.074 m^3/day	0.0021
16-18	One 15-game club season/year with 15 associated practice days; one 10-week high school season (6 days/week)	3.8 m^3/day	90 days/365 days	3 years/70 years	0.040 m^3/day	0.0006
19-22	One 15-game club season/year with 15 associated practice days; one 12-week college season (6 days/week)	6.4 m^3/day	102 days/365 days	4 years/70 years	0.102 m^3/day	0.0015
23-55	One 15-game club season/year with 15 associated practice days	6.4 m^3/day	30 days/365 days	33 years/70 years	0.248 m^3/day	0.0034
Total					0.464 m^3/day	

[1] Estimated age intervals for each soccer play scenario.
[2] Estimated play scenarios, with game or practice times as shown in Table 6.
[3] From fourth column of Table 6.
[4] Estimated games and practices per year for the corresponding play scenario.
[5] Estimated years of play for the corresponding play scenario.
[6] Calculated by multiplying columns three, four and five.
[7] Body weight means for combined males and females over each interval were: 35.6 kg for the 5-15 interval, 67.5 kg for the 16-18 interval (US EPA, 2002); 67.2 kg for the 19-22 interval, 74.0 kg for the 23-55 interval (US EPA, 1997).

Estimating the increased cancer risk from inhaling air above artificial turf fields

Eight of the chemicals identified in the air above indoor artificial turf fields (Dye et al., 2006) also appear on the California Proposition 65 list of chemicals known to the state to cause cancer (PAHs below 0.001 μg/m^3 were not included). Table 8 shows the increased lifetime cancer risks from breathing each of these during soccer play on artificial turf fields. The risk for each chemical was calculated using the highest air concentration from among eight independent measurements over three different artificial turf fields (Dye et al., 2006). This may overestimate the true chemical concentration in the air. Risks for two age intervals per chemical were calculated, so that a safety factor of three could be added for the 5-15 year interval (US EPA, 2005). Five of the eight chemicals were associated with increased lifetime cancer risks that exceeded the broadly accepted negligible risk level of 10^{-6}: benzene, formaldehyde, naphthalene, nitromethane and styrene. Their increased cancer risks ranged from 1.6 x 10^{-6} for formaldehyde to 8.7 x 10^{-6} for nitromethane. Since these risks exceeded the 10^{-6} benchmark, it is important for future studies to measure the concentrations of these chemicals above outdoor artificial turf fields. In addition, their concentrations should be measured in the ambient air in the vicinities of the fields. Comparing the concentrations in the air over and off of the fields will establish which carcinogenic chemicals are emitted by artificial turf, and whether mitigation measures are required.

Table 8. Inhalation of chemicals from above artificial turf fields in indoor stadiums in Norway that also appear on the California Proposition 65 list of chemicals known to the state to cause cancer: increased lifetime cancer risks from soccer play.

Chemical	Age inter-val in years	[1]Daily field air intake in m^3/kg-d	[2]Indoor field air concentra-tion of chemicals in mg/m^3	[3]Daily chemical intake in mg/kg-d	[4]Safety Factor	[5]Cancer Slope Factor in (mg/kg-d)$^{-1}$	[6]Increased lifetime cancer risk
Acetaldehyde	5-15	0.0021	0.0043	9.03 x 10^{-6}	3	0.01	5.0 x 10^{-7}
Acetaldehyde	16-55	0.0055	0.0043	2.37 x 10^{-5}	1	0.01	
Benzene	5-15	0.0021	0.0024	5.04 x 10^{-6}	3	0.1	2.8 x 10^{-6}
Benzene	16-55	0.0055	0.0024	1.32 x 10^{-5}	1	0.1	
Benzo[a]pyrene	5-15	0.0021	1.2 x 10^{-6}	2.52 x 10^{-9}	3	3.9	5.5 x 10^{-8}
Benzo[a]pyrene	16-55	0.0055	1.2 x 10^{-6}	6.6 x 10^{-9}	1	3.9	
Ethylbenzene	5-15	0.0021	0.0067	1.41 x 10^{-5}	3	0.0087	6.8 x 10^{-7}
Ethylbenzene	16-55	0.0055	0.0067	3.69 x 10^{-5}	1	0.0087	

Chemical	Age inter-val in years	[1]Daily field air intake in m^3/kg-d	[2]Indoor field air concentra-tion of chemicals in mg/m^3	[3]Daily chemical intake in mg/kg-d	[4]Safety Factor	[5]Cancer Slope Factor in $(mg/kg\text{-}d)^{-1}$	[6]Increased lifetime cancer risk
Formaldehyde	5-15	0.0021	0.0065	1.37×10^{-5}	3	0.021	1.6×10^{-6}
Formaldehyde	16-55	0.0055	0.0065	3.58×10^{-5}	1	0.021	
Naphthalene	5-15	0.0021	0.0027	5.67×10^{-6}	3	0.12	3.8×10^{-6}
Naphthalene	16-55	0.0055	0.0027	1.49×10^{-5}	1	0.12	
Nitromethane	5-15	0.0021	0.0041	8.61×10^{-6}	3	0.18	8.7×10^{-6}
Nitromethane	16-55	0.0055	0.0041	2.26×10^{-5}	1	0.18	
Styrene	5-15	0.0021	0.0061	1.28×10^{-5}	3	0.026	1.9×10^{-6}
Styrene	16-55	0.0055	0.0061	3.36×10^{-5}	1	0.026	

[1] From last column in Table 7. For the 16-55 interval, the value of 0.0055 is the sum of the values for the 16-18, 19-22 and 23-55 age intervals in Table 7.
[2]Dye et al., 2006; highest value from among eight independent measurements over three different artificial turf fields in indoor stadiums.
[3]Calculated by multiplying column three by column four.
[4]Safety factor for the increased sensitivity of 2-15 year old children to carcinogens (US EPA, 2005).
[5]All cancer slope factors were taken from the OEHHA Toxicity Criteria Database available at www.oehha.ca.gov except for nitromethane and styrene; nitromethane cancer slope factor is available at www.oehha.ca.gov/prop65/law/pdf_zip/NitromethaneNSRL120707.pdf ; styrene cancer slope factor from OEHHA, 2009, Public Health Goal for Styrene, under review.
[6]Increased lifetime cancer risks due to each chemical were calculated by multiplying columns five, six and seven and adding together the resulting risks for the two age intervals.

Estimating the risk of developmental/reproductive toxicity from inhaling air above artificial turf fields

Benzene and toluene were the two chemicals identified in Dye et al. (2006) that also appear on the California Proposition 65 list of chemicals known to the state to cause developmental/reproductive toxicity. Toluene is listed as a developmental toxicant, while

benzene is listed as a developmental and male reproductive toxicant. For developmental toxicants, the subpopulation most at risk is pregnant females. Were a pregnant female to use these fields for a two hour interval, her exposure to benzene and toluene via inhaled air would be below the corresponding maximum allowable dose level (MADL, Table 9).

Table 9. Daily intake rates of chemicals inhaled via air from above artificial turf fields in indoor stadiums in Norway that also appear on the California Proposition 65 list of chemicals known to the state to cause developmental/reproductive toxicity: comparison to maximum allowable dose levels (MADLs).

Chemical	**Indoor field air concentration detected in Norwegian study (ug/m^3)[1]**	**Chemical intake via field air (not averaged over lifetime) (ug/day)[2]**	**MADL (ug/day)[3]**
Benzene	2.4	15.4	49
Toluene	85	544	13,000

[1] Dye et al., 2006; highest value from among eight independent measurements over three different artificial turf fields in indoor stadiums.
[2] Calculated by multiplying the daily intake of field air for 19 to 55 year-olds (6.4 m^3/day, Table 6) by the field air concentration shown in column two of this table.
[3] MADL = maximum allowable dose level, accessed 6/08 at http://www.oehha.ca.gov/prop65/pdf/2008MayStatusReport.pdf .

This section estimates the risk of cancer or developmental/reproductive toxicity in soccer players using the new generation of artificial turf playing field. A single study (Dye et al., 2006) was used as the source of VOC and PAH concentrations from above this type of field. Since Dye et al. (2006) was performed in indoor soccer stadiums, we believe it likely that the chemical concentrations over outdoor fields would be significantly lower, due to the dispersion of the chemicals into the atmosphere. Comparing Dye et al. (2006) to IBV (2006), as shown in Table 2 of this report, suggests that this is indeed the case. Support also comes from comparing the benzothiazole concentration measured indoors by Dye et al. (2006) to that measured by Milone & MacBroom (2008) outdoors: 31.7 compared to 1.0 $\mu g/m^3$. Thus, the daily chemical intakes calculated in Tables 8 and 9 probably overestimate the intakes that would result from breathing air over outdoor artificial turf fields. More accurate estimates of the cancer and developmental/reproductive hazards will be possible when air from above additional outdoor synthetic turf fields is analyzed, along with background levels from off of the fields.

The lifetime soccer play scenarios are not based on data but on personal experience and informal discussions. Relevant data may exist that will help reduce the uncertainty in this component of the exposure assessment. Until those data are located, we consider this cumulative play scenario from ages 5 through 55 exclusively on artificial turf to represent a heaviest use scenario for soccer players. However, soccer is only one of many sports played on today's artificial turf fields. Football, lacrosse, baseball, softball and rugby are some others, along with the unorganized, informal play that predominates for young

children under the age of five. All these modes of play have characteristic ages for participants, years of expected play, and time spent on the field per game. This will result in chemical exposures via inhalation that are different from those calculated above for soccer. In addition, the people who coach, supervise or referee these sports will each have different exposures, as will the people who maintain artificial turf fields. Therefore, the risks calculated for soccer players in Tables 8 and 9 should not be interpreted as covering the risks for other sports, age groups or occupations.

Lastly, it should be noted that most of the VOCs detected above artificial turf fields in the Dye et al. (2006) study were never identified. For example, for the field yielding the highest level of total volatile organic compounds (TVOCs, 716 ug/m^3), 85 percent of the individual chemicals (representing about 20 percent of the mass of TVOCs) were not identified. This remains a significant source of uncertainty in assessing the health risks posed by these fields.

Conclusions

- The Dye et al. (2006) study provided the most complete dataset from which to calculate inhalation exposures to chemicals in the air above artificial turf playing fields.
- Lacking published data, the time that soccer players spend on artificial turf over a lifetime was estimated.
- Dye et al. (2006) quantified eight chemicals that appear on the California Proposition 65 list of chemicals known to the state to cause cancer.
- Estimated inhalation exposures of soccer players to five of these (benzene, formaldehyde, naphthalene, nitromethane and styrene) gave theoretical increased lifetime cancer risks that exceeded the insignificant risk level of 10^{-6} (OEHHA, 2006).
- Data from indoor fields were used to estimate outdoor exposures and calculate these cancer risks. In addition, it was assumed that all organized soccer play over a lifetime occurred on artificial turf fields. Together, these assumptions tend to overestimate the cancer risks for soccer players using artificial turf fields.
- Benzene and toluene were the two chemicals quantified by Dye et al. (2006) that also appear on the California Proposition 65 list of chemicals known to the state to cause developmental/reproductive toxicity. Their concentrations in the air over indoor artificial turf fields were below the associated screening levels for developmental/reproductive toxicity. This suggests there is a low risk for such health effects due to inhalation exposures in soccer players.

Data Gaps

- To calculate the inhalation health risks from outdoor artificial turf fields, an air sampling study similar to Dye et al. (2006) is needed, but it should be performed over outdoor fields, including ambient air samples from off of the fields.

- For more accurate exposure estimates, better data are needed for the hours per day, days per year, and years per lifetime that athletes spend using artificial turf playing fields. Data are needed for a variety of sports, ages and for both female and male athletes. Use of these fields for informal play by children under the age of five should also be considered.
- Exposures to professionals such as coaches, referees and maintenance workers should also be estimated.
- Approximately 300 of 400 VOCs detected by Dye et al. (2006) were not identified, so that their health risks cannot be determined.
- Since the airborne particulates measured by Dye et al. (2006) were not analyzed for metals, including lead, the health risks they pose via inhalation cannot be determined.
- While most of the VOCs identified by Dye et al. (2006) do not have MADLs developed under Proposition 65, data exist indicating that some cause developmental/reproductive effects in test animals. Thus, additional screening is required to more fully evaluate these risks.
- Health risks due to high levels of total volatile organic compounds (TVOCs) have not been adequately assessed.
- The variable of field age should be investigated since chemical release may decrease with time, leading to lower health risks. Conversely, particulate release may increase with time.
- One possible mitigation measure that should be investigated for indoor fields is to increase the ventilation rate.

Part II: Artificial Turf as a Possible Risk Factor for Infection by Methicillin-resistant *Staphylococcus aureus* (MRSA)

Is artificial turf a risk factor for infection by MRSA?

Staphylococcus is a genus of gram positive bacteria commonly found on the surface of human skin. These bacteria can infect the skin, causing diseases such as impetigo and boils. *Staphylococcus aureus* (*S. aureus*) is a species that is particularly pathogenic to humans. Besides infecting skin, it can also cause food poisoning. If *S. aureus* from a skin infection moves internally, it can spread throughout the body, causing serious organ damage. Normally, only a small percentage of *S. aureus* skin infections progress to the point where hospitalization is required.

Methicillin is a broad spectrum antibiotic often used to treat *S. aureus* infections. However, methicillin-resistant *S. aureus* (MRSA) has developed. A number of outbreaks of MRSA have occurred in athletic teams, including high school, college, professional and club teams. Thus, it is important to identify modes of transmission of MRSA and other risk factors for infection.

MRSA outbreaks in human populations are considered to be one of two kinds. Outbreaks in hospitals often occur in persons with weakened immune systems. This is considered healthcare-associated MRSA. Outbreaks in the general community, in otherwise healthy individuals, are considered community-associated MRSA. Risk factors for community-associated MRSA include young age and playing a contact sport (Boucher and Corey, 2008). In the case of athletes, this may be due in part to the frequent physical contact that occurs during play, as well as the propensity of these athletes to have skin cuts and abrasions.

A number of community-associated outbreaks of *S. aureus* and MRSA have been described in sports settings (Table 10; Lindenmayer et al., 1998; MMWR, 2003; Huijsdens et al., 2006; Turbeville et al., 2006; Kirkland and Adams, 2008). The outbreaks included boils (furunculosis), other types of skin abscesses such as impetigo, and cellulitis. In a review of the sports medicine literature (59 infectious disease outbreaks between 1922 and 2005) by Turbeville et al. (2006), the most common causes of outbreaks were *S. aureus* (often MRSA, 22 percent of outbreaks) and herpes simplex virus (22 percent of outbreaks). The sports with the most outbreaks were football (34 percent of outbreaks), wrestling (32 percent of outbreaks), rugby (17 percent of outbreaks) and soccer (3 percent of outbreaks). These are all considered contact sports, with player-to-player contact that ranges from incidental to violent. However, these sports also result in forceful impacts between the players and the playing surface. In the cases of football, rugby and soccer, the surface would usually be an outdoor field of natural or artificial turf. For wrestling, the surface would most often be a vinyl-covered wrestling mat.

The outbreaks mentioned above suggest two possibilities for the high incidence of *S. aureus* skin infections in contact sports: the bacteria are transferred by player-to-player contact or by player contact with a contaminated playing surface. The data from health-care associated MRSA outbreaks, as well as those from sports-associated MRSA outbreaks (Turbeville et al., 2006; Benjamin et al., 2007; Boucher and Corey, 2008; Cohen, 2008; Kirkland and Adams, 2008), suggest that person-to-person contact is a major mode of MRSA transmission. Whether contact with outdoor playing surfaces, such as occurs during falls to the surface, promotes transmission of MRSA is less certain.

An association between MRSA infection and player-to-playing surface contact could have at least two different explanations. Such contacts could cause relatively long-lasting skin abrasions that serve as efficient portals of entry for MRSA, perhaps during subsequent player-to-player contacts. Alternatively, the playing surface itself might be a carrier of MRSA, such that player contact with the surface transfers MRSA to the previously uncontaminated skin.

An association between skin abrasions due to falls to the turf (termed turf burns) and skin infection by MRSA has been tested in two MRSA outbreaks among football teams. In a college football team, players with MRSA-induced boils were 7.2-fold more likely to have had skin abrasions from artificial turf (new generation) than uninfected players (Begier et al., 2004). Comparative data for burns received from natural turf were not presented. In a professional football team, eight of eight MRSA-induced skin abscesses occurred at the site of a turf burn. Whether the turf burn was received on artificial (old generation Astroturf®) or natural turf was not reported. The results of these two studies demonstrated an association between skin trauma due to falls to the playing surface and skin infections by MRSA. This suggests that traumatized skin is more susceptible to MRSA entry and infection. An association between skin trauma and MRSA infection has been suggested in other outbreaks among competitive sports teams, where skin trauma was produced by other means, including irritation by protective equipment (MMWR, 2003), body shaving (Begier et al., 2004) and falls to wrestling mats (Lindenmayer et al., 1998). Other studies also support an association between skin trauma and MRSA infection during contact sports (Bartlett et al., 1982; Sosin et al., 1989; Cohen, 2008; Kirkland and Adams, 2008). In consideration of these data, it seems justified to consider skin trauma in general, and turf burns in particular, to be risk factors for MRSA infection during competitive contact sports. Whether the incidence or severity of turf burn is greater on the new generation of artificial turf compared to natural turf is discussed below.

As mentioned above, a second possible explanation for why player-to-playing surface contact might be a risk factor for MRSA infection in competitive sports is that the playing surface itself is a source of MRSA. An inanimate object capable of transmitting infectious bacteria to humans is called a fomite. While player-to-player contact is considered the most important mode of sports-associated MRSA transmission, possible

Table 10. Sports-related skin abrasions and infections on artificial and natural turf

Reference	Sport	Turf type	Endpoint	Findings
Keene et al., 1980	American football at U. of Wisconsin	Old-generation Tartan Turf®	"Scrapes"	Significantly more ($p<0.001$) scrapes on artificial turf than on natural grass
Bartlett et al., 1982	High school American football	Not indicated	Boils (furunculosis) caused by *S. aureus*	Frequent open wounds or bruises were risk factors ($p<0.05$) for boils; concluded wounds and bruises are portals of entry for *S. aureus* into the body
Ekstrand and Nigg, 1989	Soccer played at different levels	Old-generation artificial and natural turf	"Abrasion injuries"	In three different studies, there were more abrasion injuries on artificial turf than on natural turf (severity not indicated)
Sosin et al., 1989	High school American football and basketball	Natural turf (wood floors for basketball)	Boils (furunculosis) caused by *S. aureus*	Players with >2 skin abrasions/week had 2.7-fold higher risk of infection ($p<0.01$); fomite contact not a risk factor
Begier et al., 2004	American football, one college team	New (third) generation artificial turf	MRSA-induced cellulitis and skin abscesses	Infected players were 7.2-fold more likely to have "turf burns" from artificial turf than uninfected players
Meyers and Barnhill, 2004	High school American football	New (third) generation artificial turf and natural turf	Injuries, including 0-day time loss (i.e., mild) and 1-22+ days time loss injuries	"Surface/epidermal injuries"(abrasions, lacerations and puncture wounds) were 9-fold more common on artificial turf compared to natural turf
Kazakova et al., 2005	Professional American football, one team	Old-generation Astroturf® and natural turf	MRSA-induced skin abscesses	8/8 infections occurred at site of turf burn; players reported more and more serious turf burns for games on artificial turf (2-3 per week); field swabs of artificial turf were negative for MRSA
Ekstrand et al., 2006	Elite soccer in Europe (male only)	New (third) generation artificial turf and natural turf	Time loss injuries	No difference in overall injury rate on artificial and grass; did not report skin abrasions, most of which are probably 0-day time loss
Benjamin et al., 2007	Various sports	Not indicated	MRSA infection	There is little evidence that MRSA infection occurs via fomite transmission; infection probably due to skin-to-skin contact
Fuller et al., 2007a	Collegiate soccer, male and female, matches only	New (third) generation artificial turf and natural turf	Time loss injuries occurring during matches	Overall injury incidence and severity similar on artificial and natural turf; only lacerations/skin lesions in men were higher (2.95-fold, $p<0.01$) on

Reference	Sport	Turf type	Endpoint	Findings
				artificial turf (relatively serious since they were time loss)
Fuller et al., 2007b	Collegiate soccer, male and female, training only	New (third) generation artificial turf and natural turf	Time loss injuries occurring during training	All injuries similar incidence and severity on artificial and natural turf
Steffen et al., 2007	Female soccer, under-17 league	Second and third generation artificial turf and natural turf	Acute, time loss injuries	Overall injury rate was the same on the artificial and natural turf; did not report skin abrasions, most of which are probably 0-day time loss
Andersson et al., 2008	Male elite soccer	New (third) generation artificial turf and natural turf	Number of standing and sliding tackles per player per game	Fewer sliding tackles on artificial turf compared to natural turf ($p<0.05$), possibly related to the risk of turf burn
Cohen, 2008	Various sports	Not indicated	MRSA infection	Risk factors identified: 1)skin-to-skin contact, 2)skin damage (such as mat burns in high school wrestling), 3)sharing equipment (e.g., towels)
McNitt et al., 2008	Not discussed	New (third) generation artificial turf and natural turf in Pennsylvania	Bacterial colony forming units (CFUs) cultured from turf samples	Rubber crumb from artificial turf yielded fewer CFUs on a per gram basis than soil from natural turf; no colonies were positive for *Staphylococcus aureus*
FIFA, undated	Male soccer, under-17 world championship games	New (third) generation artificial turf and natural turf	Time loss and total injuries during games	Overall injury incidence similar on the two surfaces

instances of fomite transmission have been reported. A MRSA outbreak in fencers is noteworthy, since this sport does not involve person-to-person contact (MMWR, 2003). The fencers used sensor wires under their protective clothing, which were shared by multiple fencers without cleaning. The wires were possible fomites for MRSA transmission in this outbreak. Shared soap bars were identified as a risk factor in a MRSA outbreak in a collegiate football team (odds ratio, 15.0; 95 percent confidence interval 1.69-180) (Turbeville et al., 2006). A shared weight room was the only common point of contact between a high school football team and the dance team (Kirkland and Adams, 2008). While only two football players and one dance team member became infected with MRSA, this may represent an example of fomite transmission. In a MRSA outbreak among members of a high school wrestling team, no risk factors for infection could be identified (Lindenmayer et al., 1998). Nonetheless, the study authors speculated that although most cases of transmission were probably due to wrestler-to-wrestler contact, the sharing of towels and locker room equipment, as well as shared wrestling mats, may have contributed. In emphasizing that fomite transmission of MRSA should be prevented, the National Collegiate Athletic Association (NCAA) medical guidelines recommend disinfecting wrestling mats before use.

One way to determine whether artificial turf is a reservoir for infectious MRSA is to inoculate bacterial cultures with various turf components or wipe test the components to measure bacterial growth. Very few such data have been collected from potential fomites associated with outbreaks of sports-associated MRSA, including artificial and natural turf. Following an outbreak of MRSA in a high school wrestling team, environmental sampling of the wrestling facilities failed to detect any MRSA (Lindenmayer et al., 1998). During a MRSA outbreak in a professional football team, environmental sampling included the stadium's artificial turf field, weight-training equipment, towels, saunas, steam rooms and whirlpool water (Kazakova et al., 2005). For the field sampling, one-foot square areas of Astroturf® located in the parts of the field with the highest numbers of tackles were wipe-sampled. No MRSA was detected; however, methicillin-sensitive *S. aureus* (MSSA) was detected in two samples of whirlpool water and on a gel-applicator stick used for taping ankles. The most recent test of whether artificial turf harbors MRSA is a study in which twenty new generation artificial turf fields were sampled at two locations per field (McNitt et al., 2008). The artificial blades of grass and infill material (crumb rubber or crumb rubber/sand mix) were sampled separately for bacterial culture. All field samples were negative for *S. aureus*. Quantitative data were only presented for the infill samples. Those samples contained unidentified bacteria at levels ranging from 0 to 80,000 colony forming units (CFUs) per gram of infill. In comparison, two samples of natural soil yielded 260,000 and 310,000 CFUs per gram of soil. *S. aureus* was detected on a number of surfaces including football blocking pads, weight equipment, a stretching table and used towels, demonstrating that the detection method for *S. aureus* was functional. Thus, considering the three studies described above, there is no evidence that artificial turf fields harbor *S. aureus* in general, or MRSA in particular. While these conclusions are based on a small number of samples, an absence of *S. aureus* from artificial turf playing fields is not unexpected, given the dry and often hot conditions of that environment.

As discussed above, skin trauma is a likely risk factor for MRSA infection in contact sports (Begier et al., 2004; Kazakova et al., 2005). Therefore, it would be informative to determine if falls to the new generation of artificial turf put players at greater risk for turf burns than falls to natural turf. It is also important to determine if the turf burns caused by artificial turf are more long-lasting or more prone to infection by *S. aureus* compared to burns received from natural turf.

Unfortunately, most injury studies comparing artificial and natural turf have concentrated on so-called "time-loss" injuries (Table 10). These are relatively serious injuries that cause at least some loss of practice or game time. The great majority of turf burns are not time-loss injuries, and would not have been monitored in those studies. However, some data on skin abrasions are available. In a study of college football played on the old generation of Tartan Turf®, players were described as acquiring significantly ($p<0.01$) more "scrapes" on artificial turf compared to natural grass (Keene et al., 1980). This was the only injury type that was significantly increased on artificial turf compared to natural turf. In a 5-year prospective study of injuries occurring on the new generation of artificial turf, both time-loss and 0-day time-loss (i.e., no playing time lost) injuries were recorded for eight high school football teams (Meyers and Barnhill, 2004). The latter category included "surface/epidermal injuries" that covered abrasions, lacerations and puncture wounds, but not contusions (i.e., bruises). This type of surface/epidermal injury had a 9-fold higher incidence on artificial turf (injury incidence rate = 0.9; 95% confidence interval = 0.5-1.4) compared to natural turf (injury incidence rate = 0.1; 95% confidence interval = 0.0-0.6). Players for a professional football team suffering a MRSA outbreak reported that skin abrasions happened more frequently and were more severe on first-generation Astroturf® (i.e., without infill) compared to natural turf, although no supporting data were presented (Kazakova et al., 2005). In a study of collegiate male and female soccer players that recorded time-loss injuries during official matches, only the incidence of "lacerations/skin lesions" in males was significantly higher (2.95-fold, $p<0.01$) on new generation artificial turf (i.e., with infill) compared to natural turf (Fuller et al., 2007a). However, this finding was not replicated in an identical study that covered injuries sustained during training (Fuller et al., 2007b). Lastly, male soccer players at the 2005 Federation Internationale de Football Association U-17 Championship in Peru played 86 matches on natural grass and 42 on new generation artificial turf (FIFA, undated). While skin abrasion incidences were not presented, the incidences of total injuries (0-day time-loss and time-loss) per player-hour were similar on the two surfaces.

Considering the small database presented above, two studies (one soccer and one football) found increased incidences of skin abrasions on the new generation of artificial turf compared to natural turf (Meyers and Barnhill, 2004; Fuller et al., 2007a), while two studies (both soccer) measured similar rates on both surfaces (Fuller et al., 2007b; FIFA, undated). No data were located on the relative severity of skin abrasions caused by the artificial and natural surfaces. Given that both studies by Fuller et al. (2007a and 2007b) only monitored time-loss injuries, these studies almost certainly missed the majority of skin abrasions, which do not cause loss of playing time. Furthermore, the FIFA (undated) study did not provide data on the incidence of skin abrasions, only on total

injury incidence. This leaves only the football study by Meyers and Barnhill (2004) as evidence that new generation artificial turf puts football players at increased risk for skin abrasions relative to natural turf. Whether this conclusion is specific for male football players competing at the high school level is unknown, until studies can be performed for other sports and age groups.

Conclusions

- Participation in contact sports is a risk factor for infection by MRSA. Football and wrestling have recorded the most outbreaks.
- Person-to-person transmission of MRSA is the major mode of infection. Transmission by inanimate objects (termed fomites), such as the playing surface, is less well established.
- Skin abrasions and other types of skin trauma are risk factors for MRSA infection in contact sports.
- Whether the new generation of artificial turf causes more skin abrasions than natural turf has only been carefully addressed in a single study (Meyers and Barnhill, 2004) of male high school football players. In that study, artificial turf was associated with a 9-fold higher incidence of "surface/epidermal injury" compared to natural turf.
- Only one study has tested whether new generation artificial turf fields harbor MRSA (McNitt et al., 2008); none was detected in 20 fields in Pennsylvania.

Data Gaps

- Additional studies are needed to test the finding of Meyers and Barnhill (2004) that new generation artificial turf is associated with more skin injuries than natural turf. Studies should cover additional sports, age groups, and female participants.
- No study has reported on the severity of turf burn by the new generation of artificial turf compared to natural turf. Severity could include susceptibility to infection as well as the time required to heal.
- Additional new generation artificial turf fields should be sampled for MRSA and other bacteria pathogenic to humans, at different depths in the fields, and from different climatic regions in California.

Part III: Summary

Five studies were located that measured chemicals and particulates in the air above the new generation of artificial turf containing crumb rubber infill from recycled tires. The chemicals and particulates in the air over artificial turf were similar to those emitted by tire-derived rubber flooring, during rubber manufacturing, and in laboratory studies of rubber crumb heated in vessels. The most complete dataset, covering indoor artificial soccer fields in Norway (Dye et al., 2006), was used to estimate the risk of cancer or developmental toxicity. This screen only addressed the inhalation route of exposure in

athletes using artificial turf fields for a lifetime of organized soccer play. Exposure estimates were used to calculate the increased lifetime cancer risk or risk of developmental toxicity for those chemicals appearing on the California Proposition 65 list. From among eight chemicals listed as carcinogens on the Proposition 65 list, exposure to five of these (benzene, formaldehyde, naphthalene, nitromethane and styrene) during a lifetime of organized soccer play exceeded the 10^{-6} negligible risk level. Since these risks exceeded the 10^{-6} benchmark, it is important for future studies to measure the concentrations of these chemicals above outdoor artificial turf fields. In addition, their concentrations should be measured in the ambient air in the vicinities of the fields. Comparing the concentrations in the air over and off of the fields will establish which carcinogenic chemicals are emitted by artificial turf, and whether mitigation measures are required.

Dye et al. (2006) also identified two chemicals appearing on the California Proposition 65 list as developmental/reproductive toxicants: toluene and benzene. Their concentrations in the air over indoor artificial turf fields were below the associated screening levels for developmental/reproductive toxicity, suggesting a low risk for such effects due to these two chemicals. This screen contains two steps that tend to overestimate the risks for both cancer and developmental toxicity. First, the screen utilizes data from indoor artificial turf fields to estimate exposures from outdoor fields. Second, the screen assumes that all organized soccer play from the ages of 5 to 55 occurs on artificial turf fields.

The scientific literature was also searched for studies addressing the possibility that artificial turf playing fields promote infection of athletes by methicillin-resistant *Staphylococcus aureus* (MRSA). While the data suggest that skin trauma is a risk factor for MRSA outbreaks in contact sports, it is less certain whether the new generation of artificial turf causes more skin trauma than natural turf. Whether artificial turf fields harbor MRSA has been tested in only a few studies. No MRSA has been detected in any indoor or outdoor natural or artificial turf field.

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Addendum, July 2009

Review of two studies released in the spring of 2009 that measured chemicals and particulates in the air above the new generation of artificial turf playing fields

Study quality and characteristics

The study of artificial turf fields containing recycled crumb rubber infill performed by New York State (2009) is the most comprehensive to date. To measure the chemicals released into the air by these fields, air sampling was performed over two fields, along with a sample taken upwind of each field to measure the ambient background. One field was four years old and one was less than one year old. Samples were analyzed for VOCs and sVOCs. Off-gassing experiments performed in the laboratory with recycled rubber crumb identified five chemicals which were added to the target list of chemicals: aniline, 1,2,3-trimethylbenzene, 1-methylnaphthalene, benzothiazole and tertbutylamine. Acceptable weather conditions for sampling were prescribed and followed (see Table 11). Particulate matter (PM_{10} and $PM_{2.5}$) in air was measured in real-time with monitors placed over or upwind of each field. In addition, particulate matter was collected by wipe and vacuum sampling of field surfaces and analyzed by microscopy.

A total of 65 chemicals were identified in the air over the four-year-old field and 85 over the one-year-old field (twenty highest concentrations shown in Table 11). For many chemicals the upwind air sample contained similar concentrations. Since eight samples were collected over each field compared to only a single upwind sample, it is likely that had more upwind samples been collected, more chemicals would have been detected in the upwind air. Most of the chemicals were tentatively identified compounds (TICs), i.e., identified by their gas chromatography/mass spectrometry (GC/MS) peaks. TICs with match qualities of less than 85 percent of the GC/MS peaks were considered “unknowns” and not included in the health evaluation (see below). Of the 19 TICs shown in Table 11, 17 fell into this category. Therefore, from among the chemicals occurring at the twenty highest concentrations, only benzothiazole, octane and nonane were evaluated for health effects. The “unknowns” in Table 11 are indicated by asterisks.

Comparing the two fields shows good agreement for VOCs and sVOCs on the target list. Air samples from over the four-year-old field contained 17 chemicals on the target list. Air samples from above the one-year-old field contained the same 17 plus an additional three. For TICs the agreement was not as close. From among the 20 largest TIC peaks corresponding to air samples from either field (Table 11), only five were reported for both fields.

Chemicals of potential concern for adverse health effects were chosen for health evaluation based on three criteria: 1) low levels in laboratory and field blanks, 2) a concentration that was at least 35 percent higher in at least one field sample compared to the upwind sample, 3) match quality of the GC/MS peaks of at least 85 percent for TICs. These criteria yielded 15 and 16 chemicals of potential concern for calculation of inhalation health risks for the four-year-old and one-year-old fields, respectively.

Table 11. Air measurements above artificial turf fields: New York State (2009) and TRC (2009)

Reference	Scenario	Chemicals/particulates measured
New York State Department of Environmental Conservation and Department of Health, May 2009	Two outdoor playing fields made of new generation artificial turf containing recycled crumb rubber infill. One field was less than one year old, the second was four years old. No precipitation the day before sampling and during sampling, sampling on two consecutive days of light to moderate winds out of a constant direction, 77 to 84°F, sampling at multiple heights above the field (a few inches, three feet, six feet), a total of eight samples collected from each field. One sample collected upwind of each field (six foot height) to measure ambient background.	VOCs and sVOCs: 65 detected over one field, 85 detected over the second field. PAHs detected (in µg/m^3): 2-dibenzofuranamine* (12), 3-dibenzofuranamine* (11), 4-dibenzofuranamine* (9), benzo[b]thiophene, 6-methyl-* (8.7). Phthalates: none detected. $PM_{2.5}$ and PM_{10}: both classes of particulates detected by real-time monitoring at approximately 15 µg/m^3, similar concentrations over field and upwind of field; microscopy of wipe and vacuum field samples detected rubber particles in the millimeter range but not in the micron range. Twenty highest VOCs and sVOCs were (in µg/m^3): cyclohexanol* (27), 5-hexen-2-ol, (.+/-.)-* (24), cyclopropane, 1-chloro-2-ethenyl-1-methyl* (23), 2-hexen-1-ol, (z)-* (22), pentanamide, 4-methyl-* (15), 1H-benzotriazole-5-amine, 1-methyl-* (13), benzenemethanol, arethenyl-* (13), nonanamide* (13), 2-dibenzofuranamine* (12), 3H-indazol-3-one, 1,2-dihydro-2-methyl-* (12), 3-dibenzofuranamine* (11), 4-dibenzofuranamine* (11), cyclopentanone-2* (10), benzene, 1-methoxy-4-(1-propenyl)-* (9.9), methanimidamide, N,N-dimethyl-N'-phenyl-* (9.6), benzo[b]thiophene, 6-methyl-* (8.7), benzothiazole (6.5), octane (6.2), nonane (3.2), 2-butene, (z)* (2.7).

*indicates tentatively identified compound (TIC) with a GC/MS peak match quality of less than 85 percent.

Table 11. (continued)

Reference	Scenario	Chemicals/particulates measured
TRC, 2009	Two outdoor playing fields made of new generation artificial turf containing recycled crumb rubber infill;	VOCs, sVOCs and metals: 8 VOCs and 1 metal were detected at the following highest concentrations (in µg/m^3): acetone (51), ethanol (22), methylene chloride (9), 2-butanone (MEK) (3), chloroform (2.9), toluene (2.7), n-hexane (2.1), chromium (1.4), chloromethane (1.1); seven tentatively identified compounds

Reference	Scenario	Chemicals/particulates measured
	one grass field for comparison. One artificial turf field was less than three years old, the other was less than one year old. Air sampling was during the summer with temperatures from 79 to 94°F, sampling performed at three feet above the surface, 4-6 air samples collected from above each field. Two air samples collected from upwind of each field to measure ambient background.	(TICs) included isobutane, pentane, 2-methyl-1,3-butadiene (a.k.a., isoprene), 2-methylbutane. PAHs: none detected. Phthalates: none detected. $PM_{2.5}$ and PM_{10}: both classes of particulates detected by real-time monitoring at 3 to 50 µg/m^3, similar concentrations over fields and upwind of fields.

Chemical concentrations in the air above the fields were compared to health-based screening levels, assuming continuous, lifetime exposures for athletes using the fields. These assumptions overestimate the risks, since athletes do not spend their entire lives on these fields. Non-cancer health effects were evaluated by calculating hazard quotients using the highest on-field concentrations. Most hazard quotients were very low, indicating a very low risk of non-cancer health effects. The highest ranged from 0.1 to 0.6 for the compounds 1,3-pentadiene, 1,4-pentadiene, (E)-1,3-pentadiene and 2-methyl-1,3-butadiene. Hazard quotients of less than one suggest that non-cancer health effects are unlikely.

Eight potential chemicals of concern were evaluated for their cancer risks based on their highest on-field air concentrations. The highest excess lifetime cancer risk was 4×10^{-5} for 1,3-pentadiene (using the cancer potency of 1,3-butadiene as a surrogate). However, the concentration of 1,3-pentadiene in the air upwind of the field corresponded to a 2×10^{-5} cancer risk. Thus, it was judged that the cancer risks posed by this chemical due to its occurrence in field air and ambient air were similar. Other potential carcinogens were either below the air concentration associated with the 10^{-6} cancer risk level or occurred in only one of eight field samples (as TICs). The report concluded that these chemical exposures did not constitute a serious public health problem, and posed small risks of either cancer or non-cancer health effects.

For the particulate matter size classes of $PM_{2.5}$ and PM_{10}, real-time monitoring of one field showed no meaningful differences between the air concentrations over the field compared to upwind of the field. Technical problems were encountered in real-time monitoring of the second field. These data suggest these fields are not a source of $PM_{2.5}$ or PM_{10}. Samples collected by wipe sampling and vacuuming both fields were analyzed by microscopy. Rubber particles were in the millimeter range. Particles small enough to be inhaled, in the 5-7 micrometer range, were crustal minerals such as quartz and calcite. Rubber particles were not in the respirable range. Both the wipe data and the air monitoring data indicate that recycled crumb rubber infill in new generation artificial turf fields is not a significant source of $PM_{2.5}$ or PM_{10}.

TRC is an engineering and consulting firm which performed a study of artificial turf fields for the New York City Department of Health and Mental Hygiene (TRC, 2009). The study included air sampling from above and upwind of the same two artificial turf fields that were sampled for the New York State (2009) study. A single grass field was also sampled for comparison. Eight VOCs and one metal were detected in the air over the artificial turf fields. Three of the VOCs (2-butanone, chloroform, and n-hexane) were not detected in any of the upwind samples or over the grass field. In addition, seven TICs were detected, with four being specific to the artificial turf (isobutane, pentane, 2-methyl-1,3-butadiene, 2-methylbutane).

Monitoring of the air over and upwind of the artificial turf fields for $PM_{2.5}$ yielded the same concentration range. $PM_{2.5}$ concentrations ranged between 3 and 50 $\mu g/m^3$ for both.

Comparing the target list chemicals detected over the artificial turf fields to those detected in the upwind samples or over the grass field, three were specific to the on-field samples: 2-butanone, n-hexane and chloroform. The concentrations of the first two chemicals were well below the corresponding New York State short-term and annual air guideline levels. Therefore, the

chemicals were not considered for risk assessment. While the chloroform concentration was above the annual guideline level, the chemical was not considered for risk assessment because its presence over the single artificial turf field was thought to have resulted from drift from a nearby swimming pool commonly treated with chlorine. From among the four TICs that were specific to the artificial turf fields, three were well below their corresponding guideline values. The fourth, isoprene, does not have a guideline value. However, since it was detected in only one air sample as a TIC, and it was not detected when a bulk sample of crumb rubber was analyzed in the laboratory, it was not considered for risk assessment. Thus, a formal risk assessment was not performed for any chemical detected by air sampling. The report concluded that health effects were unlikely to result from the types of inhalation exposures expected to occur at these artificial turf fields.

Comparing studies

Table 12. Comparison of the chemical concentrations measured in air above artificial turf fields in the studies by Dye et al. (2006) and New York State (2009)

Chemical	**Concentration in Dye et al. (2006) (µg/m^3)[1]**	**Concentration in NY State report (2009) (µg/m^3)[1]**	**[Dye]/[NY State]**
Toluene	85	1.6	53
Benzothiazole	31.7	6.5	5
p- and m-Xylene	25.5	0.8	32
Acetone	15.3	0.6	26
o-Xylene	13.1	0.3	44
4-Methyl-2-pentanone	12.7	1.2	11
Ethylbenzene	6.7	0.3	22

[1]Highest value reported

Table 12 compares the concentrations of seven VOCs detected in air samples from above indoor and outdoor artificial turf fields. From among the 20 chemicals detected at the highest levels by Dye et al. (2006) (see Table 1), these seven were also detected by New York State (2009) (see Table 11). The concentrations can be compared to determine if the indoor study measured consistently higher concentrations compared to the outdoor study. The last column in Table 12 shows that the concentrations of these seven VOCs were from 5- to 53-fold higher in the air over indoor fields compared to outdoor fields. Therefore, as discussed in this report, using the indoor values from Dye et al. (2006) to calculate health risks overestimates the risks athletes face from inhaling the air above outdoor artificial turf fields containing crumb rubber infill.

Similar to the chemical concentrations discussed above, the concentrations of particulate matter ($PM_{2.5}$ and PM_{10}) were somewhat higher for the indoor study by Dye et al. (2006). The indoor study detected $PM_{2.5}$ and PM_{10} concentrations as high as 18.8 and 40.1 µg/m^3, respectively. Ambient, background levels of particulates were not measured. Therefore, it was not possible to determine whether the particulates were released by the turf or were already present in the ambient, outdoor air. The outdoor studies by New York State (2009) and TRC (2009) did not detect these particulates above ambient, background levels (about 15 and 3-50 µg/m^3, respectively). The indoor study used a chemical marker for tire rubber (N-cyclohexyl-2-

benzothiazolamine) to quantify the rubber in the particulate matter. Rubber comprised from 23 to 50 percent of the $PM_{2.5}$ or PM_{10}. Using microscopy, the New York State (2009) study ruled out rubber as the source of the microscopic particles in the 5-7 micrometer range. Considering all three studies together, it appears that $PM_{2.5}$ and PM_{10} were at background levels in the air over outdoor artificial turf fields, but may have been present at above-background concentrations in the air above indoor fields.

Table 13 below shows a comparison of the chemicals detected in the air above the same two artificial turf fields that comprised the studies by New York State (2009) and TRC (2009). These are the eight chemicals that were specific to the air above artificial turf in the TRC (2009) study. Sampling for both of these studies was performed at the end of August and beginning of September 2008. The chemical concentrations were consistently higher in the New York State (2009) study, ranging from 1.7-fold to 85-fold higher. The reasons for these differences are unknown. These variable results highlight the difficulties faced in obtaining consistent results from potential point sources of outdoor air pollution. Despite this variability, both studies found that the chemical concentrations they measured were unlikely to produce adverse health effects in persons using these fields.

Table 13. Comparison of the chemical concentrations measured in air above the same two artificial turf fields in the studies by New York State (2009) and TRC (2009)

Chemical	**Concentration in NY State report (2009) ($\mu g/m^3$)[1]**	**Concentration in TRC report (2009) ($\mu g/m^3$)[1]**	**[TRC]/[NY State]**
2-Butanone (MEK)	-	3.0	-
Acetone	0.6	51.0	85
Chloroform	0.2	2.9	15
Chloromethane	0.1	1.1	11
Ethanol	-	22.0	-
n-Hexane	0.4	2.1	5
Methylene chloride	3.0	9.0	3
Toluene	1.6	2.7	1.7
Isobutane*	-	2.4	-
Pentane*	0.5	11.8	24
Isoprene (a.k.a., 2-methyl-1,3-butadiene)*	0.9	2.8	3
2-Methylbutane*	0.7	3.0	4

[1]Highest value reported, - not reported, * TIC

Conclusions

- The New York State (2009) report describes the most comprehensive study performed to date on the new generation of artificial turf containing recycled crumb rubber infill. Air sampling above two fields measured VOCs, sVOCs, PM_{10} and $PM_{2.5}$.

- A total of 65 chemicals were identified in the air above a four-year-old field and 85 over a one-year-old field. Many of these were detected at similar concentrations in the air samples taken upwind of the fields.
- Most of the chemicals detected were tentatively identified compounds (TICs), as identified by their GC/MS peaks, with match qualities of less than 85 percent of the peaks. Therefore, these were considered "unknown" chemicals and not evaluated for health effects.
- $PM_{2.5}$ and PM_{10} levels were the same over one field and upwind of the field, suggesting the fields are not sources of PM release.
- Chemicals of potential concern were selected and evaluated for cancer and non-cancer health effects based on their measured air concentrations and assuming continuous, lifetime inhalation by athletes using the fields. These latter two assumptions tend to overestimate the health risks.
- Hazard quotients were all less than one, indicating a low risk of non-cancer health effects. Excess, lifetime cancer risks were either below the 10^{-6} risk level, were similar for the upwind and on-field samples, or the chemical was only detected in one of eight on-field samples. Therefore, the report concluded that these fields do not constitute a serious public health problem since the risks of health effects are low.
- The study by TRC (2009), monitoring the same two artificial turf fields as the New York State (2009) study, also concluded that health effects were unlikely to result from the types of chemical inhalation exposures expected to occur to athletes using these fields.
- The concentrations of chemicals in the air over indoor fields (Dye et al., 2006) were from 5- to 53-fold higher than their concentrations over outdoor fields (New York State, 2009). This demonstrates that using data from indoor fields to calculate the health risks from outdoor fields overestimates those risks.

Data Gaps (some of which are being addressed in the current OEHHA study of artificial turf)

- Only two artificial turf fields were evaluated in the New York State (2009) study. The same two fields comprised the TRC (2009) study. Testing additional fields for the release of chemicals and particulate matter is warranted.
- Testing fields of different ages and at different temperatures would help determine how those variables affect chemical and particulate release. In particular, fields near the end of their useful lifetime should be evaluated.
- More air samples from upwind of the fields should be collected on the same days as field samples to determine if chemicals measured over the fields are also present at similar concentrations in the ambient air.
- The air above fields was not tested for airborne metals. The previously reported finding of lead in dust sampled from some artificial turf fields indicates a potential for lead and other metals to become suspended in the air and possibly inhaled. Testing field air samples for metals is warranted.
- To estimate inhalation exposures it was assumed that athletes used the artificial turf fields continuously over their entire lifetimes. This overestimates the health risks. Data covering the time athletes spend on these fields would allow more accurate exposure and risk calculations and result in reduced risk estimates.

- In the study by New York State (2009), the relatively large number of TICs with peak match qualities below 85 percent indicates that these fields release many unidentified VOCs and sVOCs ("unknowns"). Some of these were at $\mu g/m^3$ levels (Table 11). It is likely that the health risks posed by these chemicals, if any, will not be known for the foreseeable future. The presence of a relatively large number of unidentified organic chemicals in the air over these fields is a potential health risk that cannot be evaluated at present.

References

53. Dye, C., Bjerke, A., Schmidbauer, N. and Mano, S. (2006) Measurement of air pollution in indoor artificial turf halls. Norwegian Pollution Control Authority, Norwegian Institute for Air Research, Report No. NILU OR 03/2006, TA No. TA-2148/2006.
54. New York State (2009) An assessment of chemical leaching, releases to air and temperature at crumb-rubber infilled synthetic turf fields. New York State Department of Environmental Conservation and New York State Department of Health, May 2009.
55. TRC (2009) Air quality survey of synthetic turf fields containing crumb rubber infill. TRC, Windsor, Connecticut, prepared for New York City Department of Health and Mental Hygiene, March 2009.

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Synthetic Turf Safety Proven With Science

FieldTurf synthetic turf products lead the industry by setting higher performance and environmental standards. With well over 15,000 sports and landscape installations, FieldTurf is the world's most trusted brand of artificial turf and has steered a high growth industry in the proper direction by setting the strictest of environmental standards.

As the popularity of synthetic turf escalates, so has scrutiny about its usage. Over the past couple of years, natural grass pundits have raised questions about synthetic turf's potential negative impact on the environment.

Reports surrounding the environmental safety of artificial turf may, on the surface, be alarming. However, simply put, artificial turf is safe and the science is there to prove it. While FieldTurf acknowledges the concerns of the groups behind these initiatives, the truth is that their questions have already been answered. Volumes of research and testing from academics, federal and state governments like California, Massachusetts and Connecticut, and school systems have examined everything called into question about synthetic turf. In nearly every case, their conclusions suggest synthetic turf poses no health risks. One has to wonder that with all its fertilizers, pesticides, use of water and carbon emitting lawnmowers, would natural grass fare as well under similar scrutiny?

Synthetic turf is, and has always been safe. There is no legitimate scientific or medical evidence that synthetic turf poses a human health or environmental risk.

For a listing of the hundreds of studies carried out and a collection of the actual research and the factual conclusions, please download the documents at:
www.fieldturf.com/environmental-downloads

Let's review some of the key issues that were surrounding synthetic turf in the past.

LEAD

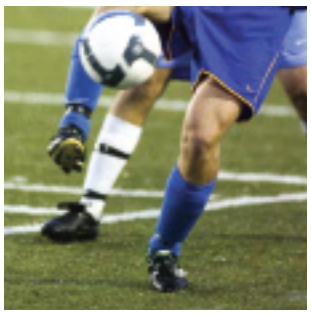
People panic when the word "lead" is mentioned, as it conjures up images of peeling paint that negatively affects a child's development. But lead chromate is very different. It was used to improve colorfastness in the pigments of many consumer products like synthetic turf. This inorganic substance is encapsulated to prevent it from being readily absorbed by the body or released into the environment. In over 40 years there has never been an instance of human illness or environmental damage caused by synthetic turf.

SO HOW DID THE MEDIA-HYPED LEAD HYSTERIA WITH ARTIFICIAL TURF START?

In April 2008, some synthetic turf fields in New Jersey were shut down by the New Jersey Department of Health and Senior Services for elevated levels of lead. However, test results have since indicated there was no lead in the air, soil or in the dust created by the removal of one of the fields. The synthetic turf fields at the Old Tappan and Demarest High Schools, which initially had been closed, were sampled on June 6, 2008. The testing found lead in the green turf fiber at concentrations of 4000 mg/kg (Old Tappan field) and 6300 mg/kg (Demarest field). However, when Dust Wipe sampling was conducted on the aforementioned Northern Valley (Old Tappan and Demarest) fields in New Jersey the values of the wipe test produced values between 10-35 µg/wipe which falls below the EPA guideline for dust on floors (40µg) and Interior Window Sills (250µg).

BOTH FIELDS WERE SUBSEQUENTLY RE-OPENED.

Over 90% of synthetic turf yarns have very low or undetectable levels of lead chromate. Lead chromate is not lead carbonate, the lead formerly found in paint. This inorganic substance is used to color the synthetic turf fiber. In synthetic turf, the silica-coated, encapsulated pigment particles are used to improve performance characteristics and reduce toxicity. Bioavailability of lead from pigment is extremely low. It is almost completely insoluble, not an inhalation hazard and not absorbed by the body if ingested.



LEAD CHROMATE

"In July 2008, a U.S. Product Safety Commission staff report concluded that synthetic turf fields are OK to install and play on for people of all ages. The evaluation of older and newer synthetic turf fields concluded that 'young children are not at risk from exposure to lead in these fields.' The report showed that newer fields had no lead or generally had the lowest lead levels. Although small amounts of lead were detected on the surface of some older fields, none of the tested fields released amounts of lead that would be harmful to children."

U.S. Consumer Product Safety Commission, July 2008, "CPSC Staff Finds Synthetic Turf Fields OK to Install, OK to Play On"

"Testing on FieldTurf fields have consistently shown 10-20 ppms or less than 5% of the lead level regarded as problematic. No cases of elevated blood lead levels in children have been linked to artificial turf on athletic fields in New Jersey and elsewhere."

Center for Disease Control (CDC), June 2008, "Potential Exposure to Lead in Artificial Turf: Public Health Issues, Actions, and Recommendations"

"Based on existing HUD Guidelines and EPA standards, lead hazard risk assessments at these four DPR synthetic turf fields did not identify lead hazards."

New York City Department of Health and Mental Hygiene, January 2008

"Lead chromate levels are well below that necessary to cause harm to children and athletes using the popular playing field surfaces. No acute health risks due to use of artificial turf fields, and risks due to chronic and repeated exposure are unlikely."

New Jersey Department of Health and Senior Services (NJDHSS), April 2008

"A sample of stormwater was collected from the drainage system of two fields on April 28, 2008, and July 24, 2008, respectively. The results showed that lead was not detected in the drainage from either field."

Milone & MacBroom, engineering, landscape architecture, and environmental science firm based in Connecticut, December 2008, 'Evaluation of the Environmental Effects of Synthetic Turf Athletic Fields'

'young children are not at risk from exposure to lead in these fields'

"Because the lead chromate is encapsulated in the fibers, it is presumed not to be bioavailable (is not released through contact) and cannot be absorbed by humans or other living systems. Research shows that contact with, or incidental ingestion of, the fibers or rubber infill poses no health risk."

Ridgewood Environmental Advisory Committee (REAC) January-October 2009, 'Assessment of Environmental, Health and Human Safety Concerns Related to the Synthetic Turf Surface at Maple Park in Ridgewood, NJ'

WHAT THE EXPERTS SAY

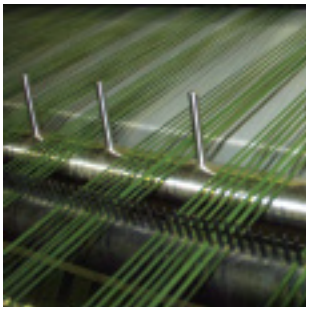
"The lead levels that were discovered are isolated to the core samples of the turf, and did not appear in the samples of dust, wipes and blades of artificial grass taken from the field - in other words, the lead is encapsulated in the fibers inside the turf and not leaching out to the surface to be ingested."

Patrick Guilmette – PMT Group; premier environmental and consulting engineering firm in NY, NJ, CT, PA

"If a green synthetic turf field containing lead chromate is still green, then the lead chromate is still in the yarn. If the Yellow Chromate had leached out, the field would likely be blue. Lead chromate is stable when encapsulated in the fiber into which it is extruded. Being encapsulated in the fiber, the lead in the lead chromate is not readily bio-available - meaning that even if the yarn breaks down, the lead in the complex compound which is lead chromate is not readily absorbed by the body."

Dr. Davis Lee, Ph.D, Synthetic Organic Chemistry, Executive in Residence at the Georgia Institute of Technology School of Polymer, Textile, and Fiber Engineering, April 2008

"In interpreting the health risk from these results, it is important to recognize that people do not ingest the actual turf fibers. The NJ and EPA soil standards of 400 mg/kg are based on an assumption that small children may ingest approximately 100 mg of soil per day through hand to mouth activity. Thus, comparing the concentration of lead in the turf fiber to an acceptable soil lead concentration is not an accurate way to evaluate the human health risk from exposure to lead in turf fibers and is likely to overestimate risk, because the turf fiber is unlikely to be ingested (if at all) to the same extent as lead in soil.



The best way to evaluate exposure to lead on synthetic turf fields is to evaluate the dust present on the surface of the field. When people play on the field, they may get dust onto their hands or other exposed skin, and transfer the dust into their mouth through normal hand to mouth activity. Thus, the primary route of exposure we are concerned with is ingestion of dust. Lead has no appreciable absorption through the skin, and the inhalation of dust from the field is expected to be minimal, as any dust is likely to adhere to the turf fiber or rubber crumb padding rather than becoming airborne."

Toxicologist Dr. Barbara D. Beck, a lecturer in Toxicology at Harvard; Former Chief of Air Toxics Staff in Region I EPA; Fellow, Interdisciplinary Programs in Health at the Harvard School of Public Health, May 2008

'none of the tested fields released amounts of lead that would be harmful to children'

CRUMB RUBBER

Crumb rubber, made from reclaimed tires, is an important part of the industry's premiere infill option for synthetic turf fields. It has been safely used in many products since being introduced in the early 1990s, and in playgrounds and tracks for much longer. The notoriously resilient SBR rubber material provides enhanced durability and cushioning to prevent injuries and keeps playing surfaces safe. Aside from its use in synthetic turf sports fields, crumb rubber is also used in a variety of products from children's rubber toys to surgical gloves to food packaging, and even in chewing gum.

With the growing popularity of synthetic turf, questions have surfaced about the safety of the little black rubber pellets that protect our athletes. Hundreds of studies have been completed to discover the truth about any potential risks of artificial turf and its components. Government health ministries and environmental bodies around the world have commissioned extensive research.

So have world health organizations, leading universities and independent scientific committees. Elected officials have reacted to the concerns of their constituents by commissioning studies to get the facts. But certain headlines reveal the tactics being used by some with a different agenda. They do not report the truth. The research has been done. The studies exist.

Read what the experts have to say in independent testing, studies and reports on the potential health and environmental impact of artificial turf.

'crumb rubber is also used in a variety of products from children's toys to surgical gloves to food packaging, even chewing gum'

INGESTION/ INHALATION

"Genotoxicity testing of tire crumb samples following solvent extraction concluded that no DNA or chromosome-damaging chemicals were present. This suggests that ingestion of small amounts of tire crumb by small children will not result in an unacceptable hazard of contracting cancer."

Enviro-Test Laboratories, Alberta Centre for Injury Control and Research, Department of Public Health Sciences, July 2003, 'Toxicological Evaluation for the Hazard Assessment of Tire Crumb for Use in Public Playgrounds'

"Based upon the current evidence, a public health risk appears unlikely. A variety of governmental bodies including Norway, Sweden, New Jersey and California have recently reviewed the health issues; their assessments have not found a public health threat. Sources of exposure unrelated to artificial turf fields are likely more important than the turf fields for many chemicals."

Connecticut Department of Public Health, October 2007, 'Artificial Turf Fields: Health Questions'

"Based on the minimal concentrations of chemicals detected, it is considered very unlikely that any significant adverse vapor (inhalation) exposures would occur to humans in close proximity to where crumb rubber is used in outdoor applications."

New Jersey Department of Environmental Protection, Division of Science, Research, and Technology, June 2007, 'Environmental Assessment and Risk Analysis - Preliminary Assessment of the Toxicity from Exposure to Crumb Rubber: its use in Playgrounds and Artificial Turf Playing Fields'

"In summary, an analysis of the air in the breathing zones of children above synthetic turf fields do not show appreciable impacts from COPCs [Contaminants of Potential Concern] contained in the crumb rubber. Therefore, a risk assessment was not warranted from the inhalation route of exposure."

New York City Department of Health and Mental Hygiene, March 2009, 'Air Quality Survey of Synthetic Turf Fields Containing Crumb Rubber Infill'

'sources of exposure unrelated to artificial turf fields are likely more important than the turf fields'

"Tire crumb does not contain chemicals with high vapour pressures, exposure via inhalation deemed low risk. Oral ingestion deemed low risk because ingestion not likely, furthermore, question of how effective stomach acids and enzymes are at extracting toxic chemicals from tire crumb and transporting them into the blood stream."

D.A. Birkholz, Director, Research & Development, ALS Laboratory Group, Edmonton, Alberta, October 2006, 'Assessing the Health and Environmental Impact from the Use of End-of-Life Tire Rubber Crumb as Artificial Turf in Sports Arenas'

DERMAL CONTACT

"Based on the available literature on exposure to rubber crumb by swallowing, inhalation and skin contact and our experimental investigations on skin contact we conclude that there is not a significant health risk due to the presence of rubber infill from used car tyres."

INTRON, commissioned by two tyre associations, and supervised by the National Institute for Public Health and the Environment and by the Ministry of Housing, Spatial Planning and the Environment in the Netherlands, April 2008, 'Follow-up study of the environmental aspects of rubber infill'

"Dermal exposure deemed low risk because carrier solvent is needed to extract toxic chemicals from tire crumb and to penetrate protective skin layers"

D.A. Birkholz, Director, Research & Development, ALS Laboratory Group, Edmonton, Alberta, October 2006, 'Assessing the Health and Environmental Impact from the Use of End-of-Life Tire Rubber Crumb as Artificial Turf in Sports Arenas'

"The uptake of PAH by athletes who have contact with crumb rubber synthetic turf is negligible. As far as dermal contact is concerned, the Norwegian Institute of Public Health and Radium Hospital (2006) carried out an extensive analysis of possible health concerns. The study found that there was no evidence to suggest that allergic reactions were caused by exposure to crumb rubber and speculated that latex in car tires was either - less available for uptake or was - deactivated as an allergen."

University of California, Berkeley and the Corporation for Manufacturing Excellence (Manex), February 2010, 'Review of the Impacts of Crumb Rubber in Artificial Turf Applications'

'there is not a significant health risk due to the presence of rubber infill'

AIR QUALITY

"Levels of chemicals in the air at synthetic turf fields do not raise a significant health concern. "

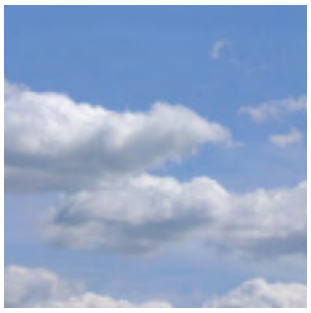
New York State Department of Environmental Conservation & New York State Department of Health, May 2009, 'An Assessment of Chemical Leaching, Releases to Air and Temperature at Crumb-Rubber Infilled Synthetic Fields'

"Twenty air samples were collected above and around two synthetic turf playing surfaces in Connecticut. Ten of the samples were analyzed for volatile nitrosamine content and 10 were analyzed for benzothiazole and 4-(tert-octyl) phenol content. The samples were collected on warm, late summer days during periods of light to calm winds. In one case, the synthetic turf surface had been groomed three days prior to the sampling. The sampling was conducted during periods when the temperature of the crumb rubber in-fill material was elevated due to exposure to the sun. The combination of air temperatures, surface temperatures, wind speed and, the recent maintenance of one of the fields, are believed to be conditions favorable for generating maximum concentrations of the analytes in the air column above and around the playing surfaces. This study determined that under favorable conditions for vapor generation, no detectable concentrations of volatile nitrosamines or 4-(tert-octyl) phenol existed in the air column at a height of four feet above the tested synthetic playing surfaces or in the air either upwind or downwind of the fields."

Milone & MacBroom, engineering, landscape architecture, and environmental science firm based in Connecticut, December 2008, 'Evaluation of the Environmental Effects of Synthetic Turf Athletic Fields'

"The majority of the studies have been on higher surface area particles and have concluded they are currently acceptable. Therefore the larger granules used in artificial turf will have even less potential for emissions. For example a study undertaken by the Danish Ministry of the Environment concluded that the health risk on children's playgrounds that contained both worn tyres and granulate rubber was insignificant. The available body of research does not substantiate the assumption that cancer resulting from exposure to SBR granulate infills in artificial turf could potentially occur."

Prof. Dr. Jiri Dvorak, FIFA, July 2006, 'An Open Letter concerning the potential cancer risk from certain granulate infills from artificial turf'



'larger granules used in artificial turf will have even less potential for emissions.'

AIR QUALITY/ VOCS & PAHS

"It is unlikely that any losses could occur to air or water in concentrations that would pose serious human or environmental risk. This opinion is supported by the reports and academic studies reviewed, which have shown insignificant environmental effects of such chemicals or release of volatiles and particulates into the atmosphere."

British Standards Institute (BSI), the Sports and Play Construction Association (SAPCA), March 2007, 'Twenty Questions [and Answers] on Rubber Granulate'

"The results of the INERIS Health Risk Evaluation, based on the concentration of the substances and worst-case scenarios, indicate that the VOC and aldehyde emissions from the three types of artificial grass fields studied in small and poorly ventilated indoor gymnasium situations are of no cause for concern for human health, for the workers installing the surfaces as well as for the general public, professional or amateur athletes, adults and children. In conclusion to its study, the INERIS stipulates that the health risks associated with the inhalation of VOC and aldehydes emitted by artificial grass fields in outdoor situations give no cause for concern towards human health."

Aliapur & Ademe (Environmental French Agency), 2007, 'Environmental and Health Evaluation of the Use of Elastomer Granulates (Virgin and from Used Tyres) as Filling in Third-Generation Artificial Turf'

"Based upon the information reviewed on PAH exposure in humans and the results of the PAH air testing performed by J.C. Broderick & Associates, the potential for exposure to PAHs during normal use of the athletic field at Schreiber and Comsewogue appears to be minimal or insignificant."

J.C. Broderick & Associates, commissioned by Schreiber High School and Comsewogue High School (NY), October 2007, 'Ambient Air Sampling for PAH's'

"The studies to date have concluded that PAHs (Polynuclear Aromatic Hydrocarbons) are not released or at most negligibly released from tyre abradate (The University of Dortmund Institute for Environmental Research 1997). Epidemiological studies conducted by the Health Effects Institute, The World Health Organisation and other investigators do not implicate tyre wear particles in ambient air as contributing to human health effects (respiratory and cardiovascular diseases)."

Prof. Dr. Jiri Dvorak, FIFA, July 2006, 'An Open Letter concerning the potential cancer risk from certain granulate infills from artificial turf'

'indoor gymnasium situations are of no cause for concern for human health'

"This study provides evidence that uptake of PAH of football players active on artificial grass fields with rubber crumb infill is minimal. If there is any exposure, then the uptake is very limited and within the range of uptake of PAH from environmental sources and/or diet."

Joost G. M. van Rooij, Frans J. Jongeneelen, 'Hydroxypyrene in urine of football players after playing on artificial sports field with tire crumb infill', September 2009.

WATER QUALITY

"There is no significant threat from chemicals leaching into surface water and groundwater. While some chemicals can be released from crumb rubber over time, they are in small concentrations and are reduced by absorption, degradation and dilution - resulting in no significant impact on groundwater or surface water. "

New York State Department of Environmental Conservation & New York State Department of Health, May 2009, 'An Assessment of Chemical Leaching, Releases to Air and Temperature at Crumb-Rubber Infilled Synthetic Fields'

"The evaluation of the stormwater drainage quality from synthetic turf athletic fields included the collection and analysis of eight water samples over a period of approximately one year from three different fields, the collection and analysis of samples of crumb rubber in-fill from the same three fields plus a sample of raw crumb rubber obtained from the manufacturer, and the evaluation of the effect of the stone base material on the pH of the drainage water. The results of the study indicate that the actual stormwater drainage from the fields allows for the complete survival of the test species called Daphnia pulex. An analysis of the concentration of metals in the actual drainage water indicates that metals do not leach in amounts that would be considered a risk to aquatic life as compared to existing water quality standards. Analysis of the laboratory based leaching potential of metals in accordance with acceptable EPA methods indicates that metals will leach from the crumb rubber but in concentrations that are within ranges that could be expected to leach from native soil."

Milone & MacBroom, engineering, landscape architecture, and environmental science firm based in Connecticut, December 2008, 'Evaluation of the Environmental Effects of Synthetic Turf Athletic Fields'

'no basis for health or environmental concern due to leaching of hazardous materials'

"Given that undiluted runoff is not likely and that three months is an outside estimate of the duration of toxicity, it is doubtful that tire crumb would present a significant risk of contamination in receiving surface waters or groundwater."

Enviro-Test Laboratories, Alberta Centre for Injury Control and Research, Department of Public Health Sciences, July 2003, 'Toxicological Evaluation for the Hazard Assessment of Tire Crumb for Use in Public Playgrounds'

"Several recent studies explored this concern in great depth and found no basis for health or environmental concern due to leaching of hazardous materials from synthetic turf installations, similar to the one at Maple Park. REAC believes that there is sufficient evidence to support the conclusion that the field design at Maple Park poses no risk to the local environment in Ridgewood."

Ridgewood Environmental Advisory Committee (REAC) January-October 2009, 'Assessment of Environmental, Health and Human Safety Concerns Related to the Synthetic Turf Surface at Maple Park in Ridgewood, NJ'

MRSA/STAPH

One of the greatest causes of public outcry has been the increased occurrence of more virulent staph infections among school-age athletes. The spread of MRSA has prompted parents and other concerned citizens to rightfully question why their children are getting sick. Recent research has proven that synthetic turf does not play a role in promoting MRSA/staph and the hysteria is often brought on by companies or lobbyists with a vested interest in anti-microbial products.

HERE ARE JUST SOME OF THE STUDIES SUPPORTING THE SAFETY OF ARTIFICIAL TURF AS IT RELATES TO MRSA/STAPH:

'the speed with which we obtained the results is a testament to how clean things are there'

"Outbreaks of antibiotic-resistant strains of staph last year gained significant media attention, resulting in the temporary closing of school buildings and athletic facilities. Our research found that infilled synthetic turf systems do not harbor significant populations of staph bacteria to warrant concern."

Dr. Andrew McNitt, Associate Professor of Soil Science at Penn State University, June 2007, 'A Survey of Microbial Populations in Infilled Synthetic Turf Fields'

The California EPA's Office of Environmental Health Hazard Assessment conducted a review of available literature entitled, Chemicals and Particulates in the Air Above the New Generation of Artificial Turf Playing Fields, and Artificial Turf as a Risk Factor for Infection by Methicillin-Resistant Staphylcoccus Aureus (MRSA). The review concluded that "there is a negligible human health risk from inhaling the air above synthetic turf and it is unlikely that the new generation of artificial turf is itself a source of MRSA."

California EPA Office of Environmental Health Hazard Assessment, July 2009, 'Chemicals and Particulates in the Air Above the New Generation of Artificial Turf Playing Fields, and Artificial Turf as a Risk Factor for Infection by Methicillin-Resistant Staphylcoccus Aureus (MRSA)'

"This confirms what we thought all along," Cole said. "The speed with which we obtained the results is a testament to how clean things are there."

Allegheny County Health Department, October 2007

'there is no connection between current generation synthetic surfaces and MRSA infections'

"There is no data to suggest that turf will ever spread MRSA. We sampled the turf for the Rams' investigation and didn't find it. We actually observed the game. We mapped where the contact on the turf occurred. We sampled those areas where the players were tackled. And then we sampled areas where there wasn't any direct contact to the turf. We didn't find any Staph or MRSA."

Jeff Hageman, Centers for Disease Control, May 2006

"In the outbreaks of MRSA, the environment has not played a significant role in the transmission of MRSA. MRSA is transmitted most frequently by direct skin-to-skin contact. You can protect yourself from infections by practicing good hygiene (e.g., keeping your hands clean by washing with soap and water or using an alcohol-based hand rub and showering after working out); covering any open skin area such as abrasions or cuts with a clean dry bandage; avoiding sharing personal items such as towels or razors; using a barrier (e.g., clothing or a towel) between your skin and shared equipment; and wiping surfaces of equipment before and after use."

Centers for Disease Control, February 2005

"We have an injury reporting tracking system and it's limited by sample size, but we haven't had any linkage to turf," said the NCAA's David Klossner. "I know there have been some reports in the media. The CDC continues to tell us that the turf is not a harbor for this MRSA/staph infection. And if things are handled appropriately as far as hygiene practices, common sense, and wound cleaning and coverage, then a lot of these things can be prevented."

NCAA Director of Health and Safety, David Klossner, November 2006

"MRSA infection has never been reported in connection with the synthetic surface at Maple Park or similar field designs. Several studies have proven that there is no connection between current generation synthetic surfaces and MRSA infections."

Ridgewood Environmental Advisory Committee (REAC) January-October 2009, 'Assessment of Environmental, Health and Human Safety Concerns Related to the Synthetic Turf Surface at Maple Park in Ridgewood, NJ'

HEAT OVERVIEW

On a hot day, things outside get hot. There may be a few stretches in the summer where people should make adjustments for play on synthetic turf, but for the majority of the year it should not be an issue.

People should also take a practical approach to the situation. Dr. Andy McNitt, head of the Penn State Center for Sports Surface Research, advises trainers to be aware of the heat when practicing in the summer on clear days. He recommends cutting down some on practice times, considering pulling players off fields earlier and taking more breaks to cool down.

HERE ARE JUST SOME OF THE STUDIES SUPPORTING THE SAFETY OF ARTIFICIAL TURF AS IT RELATES TO HEAT:

'measured air temperatures ranged from 2° F lower to 2° F greater than the ambient air temperature'

Collected data indicated that the air temperature as measured at a distance of two feet above the synthetic turf surface ranged from one to five degrees greater than the observed ambient air temperature, while the temperature at the same height above the natural turf ranged from 3° F lower to 1° F greater than the ambient air temperature. The measured air temperature at a height of five feet above the synthetic turf more closely approximated the ambient air temperature. Measured air temperatures ranged from 2° F lower to 2° F greater than the ambient air temperature.

"The results of the temperature measurements obtained from the fields studied in Connecticut indicate that solar heating of the materials used in the construction of synthetic turf playing surfaces does occur and is most pronounced in the polyethylene and polypropylene fibers used to replicate natural grass, rather than the crumb rubber particles. Rapid cooling of the fibers was noted if the sunlight was interrupted or filtered by clouds. Significant cooling was also noted if water was applied to the synthetic fibers in quantities as low as one ounce per square foot. The elevated temperatures noted for the fibers generally resulted in an air temperature increase of less than five degrees even during periods of calm to low winds."

Milone & MacBroom, engineering, landscape architecture, and environmental science firm based in Connecticut

"The study entitled 'Incidence, Mechanisms, and Severity of Game-Related College Football Injuries on FieldTurf versus Natural Grass - A Three Year Prospective Study', shows that there were double the amount of heat-related illnesses on natural grass playing surfaces compared with FieldTurf artificial turf fields."

Michael C. Meyers, PhD, FACSM, Department of Health and Human Development Montana State University

"The ambient air above both surfaces differed by only 3ºF at 12" above the surface and approximately 2ºF at 39" (the approximate chest height of a typical youth athlete). The differences in the ambient air were undetectable without a thermometer. In both cases, the ambient air temperature above the surfaces was slightly higher than the general air temperature."

Ridgewood Environmental Advisory Committee (REAC) January-October 2009, 'Assessment of Environmental, Health and Human Safety Concerns Related to the Synthetic Turf Surface at Maple Park in Ridgewood, NJ'

'there were double the amount of heat-related illnesses on natural grass playing surfaces compared with FieldTurf artificial turf fields'

IRRIGATION TO REDUCE HEAT

Ripken Experience Myrtle Beach, SC – Case Study

The Ripken Baseball Myrtle Beach Complex is the nation's premier tournament facility for baseball, complete with six FieldTurf fields to replicate some of the most famous ballparks in the history of the game.

The facility is outfitted with an irrigation system for days where the outside temperature becomes too hot and the fields need to be watered for a brief period of time. Myrtle Beach, being on the ocean in South Carolina, is a legitimate place to test the cooling effects of irrigation.

The complex has a health and safety group within Extra Bases, LLC (owner) that has mandated the temperatures where play must stop. At or about 125 degrees F (surface temperature), watering must begin.

Prior to the very first game played, the safety people and the management staff ran several tests to determine how to best water the fields. It was observed that 5 minutes (roughly 2 rotations of a typical sprinkler head) of irrigation dropped the temperature an average of 20 degrees.

Moreover, an additional 2 cycles dropped the temperature another 10 degrees. The temperatures did not breach the 125 degree F threshold for 2 to 2-1/2 hours. The ambient air temperature was in the 90's, and the sky was clear.

The tests were conducted during the most extreme of conditions around noon, when the UV was the greatest. The 125 degree F mandate is required by their insurance company, so it is not an arbitrary number.

The Ripken Baseball facility is proof of the effects of cooling because they have a lot of games played, and are situated in an area where the heating of the turf can be substantial.

'5 minutes (2 rotations of a typical sprinkler head) dropped the temperature an average of 20 degrees'

CONCLUDING REMARKS

Going Green. Eco-friendly. Environmentally safe. These are common phrases heard over and over in these turbulent times. Suddenly, the push for a clean, sustainable future is a major concern in the Western world. The recent spate of media coverage concerning artificial/synthetic turf is a prime example. Suddenly and without warning, one of the greatest advances in ecological technology is vilified, tried, and convicted—without the benefit of a fair hearing. It is important to realize that not a single injury or sickness has ever been reported anywhere in the world as a result of inhalation, ingestion, or of exposure to any of the components in the FieldTurf system.

With everything we do in our day-to-day lives, concern for a safe and healthy environment must always be of paramount importance. Certainly no one would ever imply anything different when the topic is an artificial grass playing surface. Research and testing has been and continues to be done, confirming that properly manufactured synthetic turf surfaces are a safe and sizeable contributor to an eco-friendly lifestyle.

It is important to consider all the facts surrounding the benefits of synthetic grass. As an example, recent major media publications have dealt with the nation's concern about obesity amongst our children today. At the same time, a growing population continues to put extreme pressures on the facilities within our school systems. So while educators extol the health virtues of exercise for youth, natural turf surfaces simply can't provide the 24/7 playability of synthetic turf.

'there is the ever-present issue of chemicals and pesticides applied to natural turf fields'

Another example is the potential to recycle the field at its end of life. New EPA-approved technologies allow worn-out artificial turf fields to be wholly consumed as fuel in certain plants, providing a truly "womb to tomb" environmentally sustainable solution.

Today, America's obsession with everything sports-related drives a multibillion dollar industry ever forward. Yet with record fuel prices wreaking havoc on personal, public and corporate budgets everywhere, it is tough to ignore the pockets of hypocrisy that appear in various segments of today's populace. On the one hand, there are knee-jerk reactions to such issues as crumb rubber infill and possible high levels of lead content in artificial turf.

On the other hand, there is the ever-present issue of chemicals and pesticides applied to natural turf fields—and the millions of gallons of precious water used annually to feed them. FieldTurf artificial turf fibers are produced 100 % lead-free. As the baby boom generation retires to warmer climates in the Southwest and Southeast, the strain on the finite water supply is already reaching extreme levels. We need to save the water resources for farms, not sport fields.

Hundreds of studies have been completed to discover the truth about any potential risks of artificial turf. Government health ministries and environmental bodies around the world have commissioned extensive research. So have world health organizations, leading universities and independent scientific committees. Elected officials have reacted to the concerns of their constituents by commissioning studies to get the facts. But recent headlines reveal the tactics being used by some with a different agenda. They do not report the truth.

The research has been done. The studies exist. Get the facts and find out for yourself.

Read what the experts have to say in independent testing, studies and reports on the potential health and environmental impact of artificial turf.

As the world leader in artificial grass, FieldTurf has led the way in advancing the environmental and safety benefits of artificial turf products. FieldTurf was designed not as a replacement for muddy fields but as an alternative to the best natural grass, to provide a playing surface where athletes of all ages could enjoy increased playing time on a consistently safe playing field through all weather conditions.

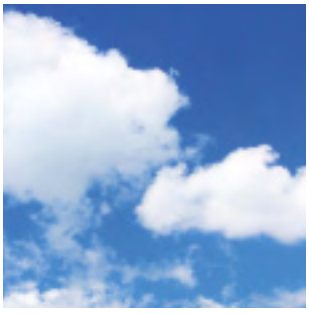
Countless studies, including a five-year study of high school football injuries and a three-year study of college football injuries, along with a multi-year study of soccer injuries, has shown that FieldTurf artificial grass significantly reduces the number and severity of injuries as compared to those recorded on natural grass.

Aside from the high volume of recycled materials used in our infill material, our artificial grass eliminates the wasteful and sometimes dangerous use of water, pesticides and chemicals, normally required to keep a natural grass field in good condition.

Countries all over the world have commissioned and executed hundreds of extensive studies to identify any potential dangers of crumb rubber (SBR). Over the past many years such research and testing has been carried out by world health associations, national health departments, municipal and federal groups, sporting associations, environmental protection groups, government ministries and official bodies of every description.

These studies originated in countries where environmental issues have always been of paramount importance. When the potential dangers were first presented, some countries even outlawed the use of SBR rubber in artificial grass fields. Every country that originally restricted or outlawed the use of SBR has reversed its position since reviewing the data and results of the comprehensive studies they instituted, especially when it comes to protecting the health of our children. But such investigation requires a more thorough approach, involving science and long-term studies as opposed to catchy headlines and political agendas.

THE RESEARCH HAS BEEN DONE. THE STUDIES EXIST. GET THE FACTS AND FIND OUT FOR YOURSELF



'FieldTurf significantly reduces the number and severity of injuries compared to natural grass'

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THE ULTIMATE
SURFACE EXPERIENCE

UNIVERSITY OF CALIFORNIA, BERKELEY
LABORATORY FOR MANUFACTURING AND SUSTAINABILITY
COLLEGE OF ENGINEERING

Review of the Impacts of Crumb Rubber in Artificial Turf Applications

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February 2010

Prepared For:
The Corporation for Manufacturing Excellence (Manex)

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LABORATORY FOR MANUFACTURING AND SUSTAINABILITY

LMAS

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EXECUTIVE SUMMARY

There are many characteristics of infill systems that have lead to resurgence in the popularity of synthetic turf. The industry has been experiencing a period of growth with the development of crumb rubber infill system, which initially debuted in 1997. These systems are preferable to the carpet-like turf of the past because they more closely resemble natural grass.

Crumb from used tires have been used in artificial turf fields for over a decade, and even longer in playgrounds and tracks. The EPA's view is that scrap tires are not hazardous waste and approves the use of crumb from used tires for sports fields. Recycled tires that were used in this capacity prevented an estimated 300 million pounds of ground rubber from scrap tires from ending up in landfills in 2007 (Rubber Manufacturers Association, 2009). In addition, this application uses recycled material; scrap tires, which otherwise would have to be handled as waste. It typically takes between 20,000 and 40,000 scrap tires to produce enough infill to cover a football field (City of Portland, 2008). The EPA's decree has afforded the opportunity for 4.5% of U.S. scrap tire to be applied as crumb rubber in sports surfacing in 2007 (Rubber Manufacturers Association, 2009).

The Corporation for Manufacturing Excellence (Manex), a National Institute of Standards and Technology Manufacturing Extension Partnership (NIST MEP), in collaboration with the Laboratory of Manufacturing and Sustainability (LMAS) at the University of California, Berkeley have studied the benefits of crumb rubber in artificial turf applications, and provide research and insight as to why this material has grown in popularity. This analysis will also include the primary features, economic benefits and other advantages that have led to the widespread expansion and adoption of artificial turf that includes the crumb rubber.

Playability is one of the primary benefits of synthetic turf, with the newer generation of infill systems exhibiting improved playability over traditional synthetic varieties. The play quality of a field is most impacted by aspects of construction and maintenance. Irrespective of the field type, the quality of play can vary dramatically according to factors such as: moisture, hardness, grass cover and root density (Orchard, 2002), naps in the turf, the distribution and compaction of infill, and infill depth (James and McLeod, 2008). Most literature comparing the play quality of natural and synthetic fields suggests that the differences between them have miniscule affects on playability in comparison with variance in the set-up of the field itself. Where differences do emerge, data is out of date and not applicable to current generations of turf technology.

Research indicates that artificial turf provides a greater number of playable hours than natural turf. Studies suggest that average hours of playability in a three-season year for synthetic turfs range between 2,000 and 3,000 hours, with most research pointing towards 3,000 hours. Natural fields, on the other hand, provide far less playability, with studies estimating a range between 300 and 816 hours in a three-season year on average. Studies show, furthermore, that switching from natural to synthetic turf results in a drastic increase of play-time. This is due, in part, to the vulnerability of natural fields to fluctuations in weather. In addition, natural fields require rest, with managers recommending against using fields more than 20-24 hours a week. Natural fields are also vulnerable to poor management, which can detract significantly from use-time.

Synthetic turf is praised for its availability in all weather conditions: more use per year, and a quick install. This factor influenced the amount of use that can be had on the turf, and thus the payback on investment on the turf. It can be used quickly after installation, usually within a few days, rather than the weeks it takes for a sod to become robust enough for use. Also, it can be used in snow, and in general is not affected by precipitation due to the drainage system involved. However, high heat can create an obstacle for synthetic turf use, as the surface can become uncomfortable to play on. It has been shown that the difference between turf temperatures and the surrounding air can be significant. However, there are means to temper such effects, and the field can still be made useable. Also, the use of turfs are not typically greatest during the hottest parts of the year, as sports seasons typically fall in the late summer through the spring. These impairments do not compare to the degree to which natural fields are compromised during rain and snow. With all weather considered, artificial turf has greater availability over natural grass when taking weather into account.

The value of a field can be determined by its availability and by amount of maintenance a field requires. The Sports Turf Managers Association (2005) states that these costs depend on: the amount of use; the type of use (i.e. sports played); climate and weather; existing soil and terrain; irrigation and water needs; labor; field type; and field security (protection against vandalism, non-regulated play, etc.). Activities that can be classified as grooming are the most important components of maintenance for both turf types. In addition, debris control, additional cleaning, and needs-specific maintenance may be required. A brief review of suggested maintenance practices produced a list of over 22 possible pieces of equipment, and 8 possible supplies for field maintenance. In general the maintenance that is necessary for a synthetic field has a similar maintenance requirement on a natural field. However, natural fields require a more nuanced balance of activities such as mowing, fertilization, and aeration to ensure their health.

One of the primary concerns for organizations considering the implementation of synthetic turf is whether it poses any significant health or injury risks. Numerous studies have been conducted assessing the likelihood of injury on natural grass and synthetic turf. Some studies reveal that there is very little difference in the rate, type, severity, or cause of injuries obtained on natural grass or synthetic turf (Fuller et al. 2007a, 2007b). A more recent study by Meyers (2010) shows that the latest generation of synthetic surface, FieldTurf, is safer to play on than natural grass fields. Through the analysis of the various injuries that occurred over the course of 465 collegiate games, Meyers shows that FieldTurf has lower incidence of: total injuries, minor injuries (0-6 days lost), substantial injuries (7-21days lost), and severe injuries (22 or more days lost). FieldTurf also had significantly lower injury rates that natural turf when comparing across play or event type, grade of injury, or various field conditions and temperatures. In addition, there was no significant difference found in head, knee, or shoulder trauma between the two playing surfaces. Meyers' (2010) research is the most comprehensive study to date, and it addresses previous inconsistencies in findings on injury patterns.

The use of athletic fields made of recycled tires has also been called into question because of concerns regarding toxicity. Authorities are worried that because of the chemical content of the material, exposure by various means could endanger the health of field users, especially children. However, extensive research has pointed to the conclusion that these fields result in little, if any, exposure to toxic substances.

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A review of existing literature points to the relative safety of crumb rubber fill playground and athletic field surfaces. Generally, these surfaces, though containing numerous elements potentially toxic to humans, do not provide the opportunity in ordinary circumstances for exposure at levels that are actually dangerous. Numerous studies have been carried out on this material and have addressed numerous different aspects of the issue. For the most part, the studies have vindicated defenders of crumb rubber, identifying it as a safe, cost-effective, and responsible use for tire rubber. As part of this study, independent product test results were obtained and reviewed for crumb rubber produced by BAS Recycling of Moreno Valley, CA, a high volume producer of cryogenic crumb rubber for synthetic turf. Test results confirm that crumb rubber is safe for use in sports and athletic field environments.

In general, the environmental impacts of natural grass are more complex than those of synthetic turf. This is due in large part to the fact that natural grass requires the continual addition of inputs to sustain a field's health. As with any agricultural practice, draws on water and the addition of agrochemicals can become problematic. These practices draw on scarce resources and have the potential to effect surrounding ecosystems. Additionally, the maintenance of grass is associated with the use of large quantities of fuel, to mow grass down to the appropriate length. The Athena Institute sufficiently shows the weight of these impacts in regards to global warming. However it is recommended that a more comprehensive inclusion of material inputs into grass maintenance be calculated in any future life cycle assessments.

The environmental issues related to synthetic turf mainly revolve around the use and disposal of materials. Many see the use of recycled waste products for field infill as one of the primary benefits of artificial systems. However, such systems also require the use of many virgin materials. As such, the greatest greenhouse gas emissions of either two system types are the impacts associated with the production of synthetic turf components. These material impacts increase the total emissions by a multiplicative factor when considering the entire life cycle, due to related increases in processing and transportation needs.

1.0 INTRODUCTION

1.1 Background

Growth in the popularity of synthetic turf has been followed by increased scrutiny of its usage. The industry has been experiencing a period of growth with the development of crumb rubber infill system, which initially debuted in 1997. These systems are preferable to the carpet-like turf of the past because they more closely resemble natural grass. They consist of longer simulated grass blades that do not compact because of the infill material that supports it. As of 2008 over 3,500 new-generation synthetic turf fields had been implemented (Jackson, 2008). In addition over half of all NFL teams currently play on synthetic turf (Synthetic Turf Council, 2008a).

There are many characteristics of infill systems that have lead to resurgence in the popularity of synthetic turf. First, it is believed that infill systems perform better than traditional synthetic turf for athletic applications (Popke, 2002). Also, artificial turf is available year around and requires less monetary and natural resources than natural grass.

Crumb from used tires have been used in artificial turf fields for over a decade, and even longer in playgrounds and tracks. The EPA's view is that scrap tires are not hazardous waste and approves the use of crumb from used tires for sports fields. Recycled tires that were used in this capacity prevented an estimated 300 million pounds of ground rubber from scrap tires from ending up in landfills in 2007 (Rubber Manufacturers Association, 2009). In addition this application uses recycled material: scrap tires, which otherwise would have to be handled as waste. It typically takes between 20,000 and 40,000 scrap tires to produce enough infill to cover a football field (City of Portland, 2008). The EPA's decree has afforded the opportunity for 4.5% of U.S. scrap tire to be applied as crumb rubber in sports surfacing in 2007 (Rubber Manufacturers Association, 2009).

1.2 Objectives

The Corporation for Manufacturing Excellence (Manex) in collaboration with the Laboratory of Manufacturing and Sustainability (LMAS) at the University of California, Berkeley has been enlisted to study the benefits of crumb rubber in artificial turf applications, and provide research and insight as to why this material has grown in popularity. This analysis will also include the primary features, economic benefits and other advantages that have led to the widespread expansion and adoption of artificial turf that includes the crumb rubber.

1.3 Scope of Work

This study identified and assessed existing research on the benefits, advantages and safety concerns of crumb rubber. A sample from a California scrap tire recycler was also assessed to support and confirm key conclusions. Material was provided from a leading cryogenic crumb rubber producer, BAS Recycling, primarily for the purpose of reviewing and assessing safety concerns. Test results from an independent lab were obtained, and then reviewed, against some of the key health concerns regarding contamination. The research provided by Berkeley sought to confirm or invalidate the following findings from existing research/studies:

- **Excellent Playability** – synthetic turf does not inhibit or deflect the bounce or roll of balls. Traction, rotation and slip resistance, surface abrasion and stability meet the rigorous requirements of the most respected sports leagues and federations.

- **All-weather Availability** – synthetic turf can be used within hours of installation, in all types of weather. No significant downtime is required in case of rain, drought or other climate conditions. Increased availability equates to higher return on investment for owners, and more practice and skill development for players. Additional questions to be answered are: whether artificial turf can be utilized more per year without the rest that grass fields require, and what the maximum hour of playing time is for the two field types.

- **Increased Playing Hours** – in most climates, synthetic turf fields can be used 3,000 hours per year over a four-season window, with no damage to the turf. Natural turf fields become unplayable after 680 to 816 hours per year, and are typically available only for three seasons.

- **Reduced Maintenance** – natural turf fields require approximately 70,000 gallons of irrigation water each week, approximately 15 to 20 pounds of fertilizer each year per 1,000 square feet of turf, plus herbicides and pesticides. Synthetic turf maintenance costs are two to three times less than natural turf. No mowing, irrigation or chemicals are required.

- **Cost-effective Investment** – synthetic turf fields are typically warranted for about 3,000 hours of play per year, with no "rest" required. For schools with sufficient land, it would take three or four natural fields to withstand the usage of one synthetic turf field. Because of its consistent availability, a synthetic turf field is also a reliable source of rental revenue for schools and communities. In addition, the total cost of ownership for fields will be explored, including all of the maintenance resources (water, fertilizer, pesticides, labor, and equipment) needed to upkeep a field.

- **Generally Safe Application** – for most common and typical uses, the materials (e.g. crumb rubber) is a safe alternative to natural materials and landscaping. While the general public is exposed to articles suggesting the need to further assess the material, no conclusive study has proven these materials as unhealthy, nor have high incidences of physical harm occurred from approved and proper uses. Recent issues that have surfaced relate to Carbon Black and Lead, however, for the vast majority of applications, serious physical harm has not occurred from these particulates.

- **Fewer Injuries** – synthetic turf fields are far more uniform and consistent than the natural turf fields most schools and communities are able to maintain. Also, they are made of resilient materials that provide a level of impact attenuation that is difficult to obtain on hard, over-used natural turf fields. An NCAA study comparing injury rates during the 2003-2004 academic year showed that the injury rate during practice was 4.4% on natural turf and 3.5% on synthetic turf.

- **Environmentally Friendly** – using synthetic turf eliminates the need for water, pesticides, herbicides and fertilizers. The used auto tire rubber used as infill recycles 25 million used auto tires per year that would otherwise end up in U.S. landfills. The EPA encourages the use of recycled auto tires for playgrounds, running tracks and sports fields.

2.0 IMPACT ANALYSIS

2.1 Playability

Playability is one of the primary benefits of synthetic turf, with the newer generation of infill systems exhibiting improved playability over traditional synthetic varieties. Research suggests that the play quality of any particular field is determined more by how the field is constructed and maintained than by the type of field material that is used. Factors such as moisture, soil compactness, and root or infill density can cause wide variance in play quality, playing a greater role in determining quality than the type of field. Components of qualitative play factors can be

organized into ball-surface interactions and player-surface interactions. (Bell, Baker, and Canaway, 1985; Schmidt, 1999)

A surface can decrease play performance and prevent players from achieving their objectives. Pasanen et al. (2007a) note that there are two factors that influence surface-related injuries: shoe-surface friction and surface hardness. Schmidt (1999) also includes surface evenness as a factor affecting player-surface quality.

Friction can impact play by leading to slippage, foot fixation, and increased running speeds resulting in collisions and ankle and knee injuries. Surface friction depends on multiple factors. Orchard (2002) notes that moisture, hardness, grass cover, and root density are turf properties that influence shoe-surface traction. Existing research comparing the rate of surface traction injuries on synthetic and natural fields is outdated, as it considers previous generations of synthetic turf rather than the current infill systems. For instance, Powell and Schootman (1992) compare injury rates of natural and synthetic fields from 1980-1989, and Orchard and Powell (2003) consider rates from 1989-1998. These studies predate the newer generation of turf, which was first implemented in 1997. In addition evaluations that attempt to compare field types may be difficult, as it has been shown other factors, such as weather, affect injury rates (Orchard and Powell, 2003). Findings such as these support the notion that shoe-surface traction impacts injury rates and play in general, but there is not sufficient evidence evaluating the affects of traction in the newer generations of synthetic turf.

Similarly, surface hardness can affect player-surface interactions. Ground reaction force is the impact energy caused by an athlete's foot striking the playing surface. This force has been cited as a risk factor in causing acute and long-term injuries (Boden et al., 2000; Chappell et al., 2007; LaStayo et al., 2003). Surface hardness is one measure used to assess the ability of the surface to absorb foot striking impacts. Brosnan and McNitt (2008a, 2008b) note that natural and synthetic turfs have comparable surface hardness values. For natural surfaces, hardness is related to the amount of soil moisture, while for infilled synthetic surfaces, infill depth is a major factor in determining surface hardness. Synthetic turf tends to provide a fairly consistent playing surface. This is partially because surfaces are leveled before the application of synthetic turf. Furthermore, synthetic surfaces are less vulnerable than natural turf to play-related damage such as divots. While factors such as the distribution of infill can impact the uniformity of synthetic fields, synthetic turfs tend to be more even throughout.

Several aspects of ball-surface interactions have been identified for evaluating play quality. Schmidt (1999) cites rebound, spin, and roll as the principle characteristics of ball-surface interaction. Meanwhile, James and McLeod (2008) list roll, bounce, spin, and deceleration as important measures of playability. Holms and Bell (1986) note the interrelationship between eleven factors on play characteristics such as rebound resilience, traction, and deceleration for natural fields.

The play quality of a field is most impacted by aspects of construction and maintenance. Irrespective of the field type, the quality of play can vary dramatically according to factors such as: moisture, hardness, grass cover and root density (Orchard, 2002), naps in the turf, the distribution and compaction of infill, and infill depth (James and McLeod, 2008). Most

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literature comparing the play quality of natural and synthetic fields suggest that the differences between them have miniscule affects on playability in comparison with variance in the set-up of the field itself. Where differences do emerge, artificial turf appears to be equal to or better than natural turf, due to its greater consistency. While such findings are incomplete, because of the lack of studies that evaluate the newer generations of turf technology, there were no studies that contradicted the superiority of synthetic turf.

2.2 All-weather Availability

Playability can also be evaluated according to its availability to users. Maintenance, weather, and resting periods are all factors influencing the amount of time that can be spent on a field. In addition, use-time plays a role in evaluating its value and the return on investment for owners. Synthetic turf has been praised for its superior availability to natural turf, their quick installation, and accessibility in all climates and weather types.

Synthetic turf can be installed quickly and is usable within hours of installation. Several professional installers quote an installation time of about two to three days, a time that can be significantly longer if the field is initially in poor condition (e.g. requires the removal of a considerable portion of the existing field). The European Synthetic Turf Organization (2010) estimates that an installations can take as long as two to three weeks. Yet once a synthetic field is installed, it can be used almost immediately, unlike sod fields, which can take up to a month to be fully functional, and seeded fields, which take considerably longer to become fully rooted.

Additionally, synthetic turf can be used in almost any climate and weather, while natural turf is more limited. Natural turf has reduced availability during rain or snow, and precipitation can cause grass turfs to become soggy or muddy. Meanwhile, snow can be difficult to remove from these fields, and may permanently damages grasses. Comparatively, winter weather conditions and precipitation are not harmful to synthetic surfaces, and if necessary snow and ice can be removed for play.

However, the playability of synthetic turfs may be hampered by hot weather conditions. The New York City Department of Health and Mental Hygiene (2010) reports that synthetic turf fields may become too hot to play on when temperatures are high. The material in synthetic turf absorbs heat, resulting in surface temperatures that are greater than surrounding air and other surfaces. However, these affects can be mitigated. Williams and Pulley (2002) found that increases in surface temperature were more impacted by solar radiation than ambient temperatures. As a result, surfaces can be made cooler when they receive less direct light exposure, like when they are painted lighter colors or are shaded. Temperature increases can also be assuaged by irrigation. Yet these solutions do not entirely mitigate hot temperatures. The difference between turf temperatures and the surrounding air can be significant. In one study, Brakeman (2004) found turf temperatures to be over 100 degrees hotter than surrounding air temperatures. In another, Williams and Pulley (2002) found synthetic surface temperatures as high as 200 degrees. Cooling effects have brief results (Williams and Pulley, 2002; McNitt, Petrunak, and Serensits, 2008) and can result in a large increase in resource use and costs.

While high heat can create an obstacle for synthetic turf use, there are means to temper such effects. Also, use of turfs are not typically greatest during the hottest parts of the year, as sports

seasons typically fall in the late summer through the spring. These impairments do not compare to the degree to which natural fields are compromised during rain and snow. With all weather considered, artificial turf has greater availability over natural grass when taking weather into account.

2.3 Increased Playing Hours

Artificial turf provides a greater number of playable hours than natural turf. The Synthetic Turf Council (2008), an artificial turf advocacy group, estimates that natural fields provide 680-816 hours of play in a three-season year, as compared with 3,000 hours for synthetic turf. Kay and Vamplew (2006) offer an alternative estimate with approximately 300 hours of play time for natural grass, 800 for reinforced turf, and 3,000 for artificial turf. James and McLeod (2008) calculate the usable hours of synthetic turf to be closer to 2,000 hours per year on average, with a range from 450 to 4,200 hours. They also note that the typical weekly hours of use for synthetic turf pitches were 44 hours, as compared to 4.1 hours for natural turf. In direct applications of synthetic turf, many note a measured increase in use-time of these field types. For instance, with a switch from natural to synthetic turf, the City of Newport Beach (2009) found a 49% increase in field availability, and the Charlottesville City Schools reported a 60% increase in available playing time.

Weather is an important factor in use-times for natural turf. While artificial turf fields recover quickly after precipitation, natural fields may take days before they become playable again. Weather-related losses in use-time can be considerable. Even in the relatively temperate climate of Newport Beach (2009), Recreation and Senior Services Department staff estimates that fields are unavailable an average of ten days a year because of rain. In addition to weather-related use-time loss, all natural fields must be given time to "rest" to allow for growth. The Synthetic Turf Council (2008) states that the managers of natural fields recommend against the use of natural fields beyond 20-24 hours per week, to avoid overburdening them. In addition, poor management can impact the availability of fields. If elements such as drainage systems and watering and maintenance schedules are improperly planned they can unnecessarily impede on the use-time of fields.

2.4 Maintenance

The maintenance required, along with the number of playing hours a surface can provide, are key factors in assessing the value that a certain turf type provides. Reduced maintenance is often cited as one of the major benefits for synthetic turf. However, artificial turf does require a minimum level of upkeep. The savings in maintenance are apparent when considering the useful hours that are returned on the cost and time required for maintenance. One estimate for an ideal level of maintenance for a synthetic field is one hour for each ten hours of use (James and McLeod (2008)). Below is a comparison of the typical maintenance requirements and their estimated durations for synthetic and natural turf.

The amount of maintenance that is needed for any field type can vary depending on a multitude of factors. The Sports Turf Managers Association (2005) states that these costs depend on: amount of use; type of use (i.e. sports played); climate and weather; existing soil and terrain; irrigation and water needs; labor; field type; and field security (protection against vandalism, non-regulated play, etc.). The proper upkeep of a field will ensure that it reaches its lifetime

potential, thereby yielding a greater return on investment. Both natural and synthetic turfs require a minimum level of upkeep to preserve surface quality. Activities that can be classified as grooming are the most important components of maintenance for both turf types. In addition, debris control, additional cleaning, and needs-specific maintenance may be required.

For synthetic fields, grooming is needed to maintain optimal play quality and proper functionality. Grooming practices include upkeep of seams, fibers, infill, and the drainage system. A broom or brush can be implemented to align the direction of fibers. Top dressing equipment and spiking equipment are employed to re-dress, redistribute, and de-compact the crumb rubber. Debris removal is also extremely important and should be done as quickly as possible to prevent more complicated problems, such as blockages in the drainage system. Sweepers, blowers, and vacuums are used to remove these materials. Additional cleaning steps may be necessary to get rid of the contaminants that cannot easily be eliminated. Pressure washing and spraying can flush the field or apply chemical agents and disinfectants. Also, depending on the specific needs of a particular field, other maintenance and equipment may be necessary. For instance, painters and scrubbers might be required to add and remove painted lines for various sports. In more severe climates and weather, snow removal is done with a plow. Irrigation systems can be helpful in environments with high temperatures, or when specified in warranty agreements. Additionally, any chemicals needed for the weed control, cleaning, and static-minimization are applied through spraying equipment.

Maintenance for natural turfs is also primarily focused on grooming. Mowing, watering, fertilizing, plant-protectant application, aeration, and irrigation should be carried out as necessary to ensure the proper growth of grass. In addition, debris may need to be removed, although the impact of debris is generally of less consequence than for artificial systems. Again, much like synthetic turf, there may be special equipment required for the specifics use needs of a field, such as painters, plows and sprayers.

An expanded list of possible maintenance requirements and their associated equipment has been complied in Table 1 below. The information in this table has been collected from various studies that discuss the possible maintenance entailed for a synthetic or natural turf system. For the purpose of identification each reference was assigned a number, which is then listed in the table when the reference suggests a specific type of maintenance. Maintenance needs can be categorized into seven types: general needs; debris removal, grooming, surface maintenance, systems, turf restoration, and user specific needs. From these, 13 specific needs were identified, with 22 pieces of associated equipment and 8 supplies. Additional maintenance factors that were suggested for inclusion were labor, weeding, and seam repairs. We will assume that all maintenance will require labor, and the differences in labor costs are included in Section 2.5.3, Table 2.6. Weeding is an activity that has been suggested for synthetic turfs by the Turfgrass Resource Center (2008) and Patton (2009). This activity does not need to be individually considered, as it is covered by the inclusion of labor and hand tool equipment. Lastly, seam repairs may be necessary, but are assumed to occur only a few times over the life span of a synthetic turf. If such repairs are necessary, it is assumed that they will be done by a contractor, so as to not violate any warranty on the turf. These three aspects will not be considered for the remainder of this section.

Table 2.1: Equipment and Supplies Recommended for the Maintenance of Fields				
Category	**Purpose**	**References that Recommend Maintenance Type**		**Equipment & Supplies**
		Synthetic	**Natural**	
General	Transport	1, 3, 4, 5, 9	1, 4, 9	**Equipment**: tractor/utility cart for operating equipment
	Small Tasks	3, 4	4	**Equipment**: assorted hand tools (i.e. rakes, hammers, edger, etc)
Debris Removal	Clearing of Objects	1, 3, 4, 5, 6, 9	1, 4*, 9	**Equipment**: sweepers/blowers to remove surface debris
		1	4*, 9	**Equipment**: vacuum to remove small items
		5, 9		**Equipment**: field magnet dragged to capture metal objects
	Cleaning/ Clearing of Contaminants	1*, 3, 4*		**Equipment**: pressure washers/flushing equipment remove unwanted fluids or contaminants
		6, 9		**Supply:** chemical disinfectants
Grooming	Grass & Fiber Blades upkeep	1, 2, 3, 4, 5, 6, 9	9	**Equipment**: broom, brush or tine dragged to realign fibers and to distribute the crumb rubber
		5, 9	9	**Equipment**: roller keep fibers from forming grain
			1, 4, 9	**Equipment**: mower
Surface	Soil/Infill Compaction, Reapplication & Redistribution	1*, 3*		**Equipment**: spiking equipment: de-compaction, redistribution of crumb rubber
		1, 4, 9	1*,4*, 9	**Equipment**: top dressing equipment: for crumb rubber loss
		6, 9	9	**Supply:** top dressing (additional crumb/sand)
	Fertilizing		8, 9	**Equipment**: seed/fertilizer spreader
			1, 4, 9	**Supply:** fertilizer
	Aeration		1*	**Equipment**: de-thatching equipment
			1*, 4*, 9	**Equipment**: (deep tine) aerator
			4*	**Equipment**: core harvester: collect cores that are pulled to the surface following aeration. can be used to gather thatch, similar to a sweeper.
	Protectant application (Weeds, Static)	1, 4, 5, 9	1, 4	**Equipment**: spraying equipment: for the application of weed control, pest control, cleaning agents, wetting agents to lessen the static charge to aid in drainage.
			9	**Supply:** pesticides
		2, 6		**Supply:** sprays to reduce static (fabric softener)
Systems	Watering	1*, 4*	1*, 4*, 9	**Equipment**: irrigation system: for watering, cooling, and warranty requirements
		4*	4*	**Equipment**: hoses/nozzles: small scale irrigation (syringing)
		7, 9	9	**Supply:** water
Restoration	Lawn Renovation		1*	**Equipment**: groove or slit seeder
		7	8, 9	**Supply:** seeds/sod replacement
Needs Specific: Weather, Play Type	Painting	1*, 4*, 5, 9	1*, 4*, 9	**Equipment**: painters: adding lines
		6, 9	8, 9	**Supply:** paint
		4*		**Equipment**: mechanical scrubbers: cleaning painted lines on the synthetic turf.
	Snow Removal	3*	1*, 4*	**Equipment**: special rubber blade snow plow

*indicates the item was suggested as optional

References for Table 2.1

1) Sports Turf Managers Association (2005)
2) Patton (2009)
3) FIFA (2001)
4) Sports Turf Managers Association (2006)
5) "Synthetic Turf Maintenance Equipment" (Brakeman 2005)
6) "2004-2005 Maintenance Budget Synthetic Infill Field" (Brakeman 2005)
7) Chirillo (2008)
8) New Yorkers for Parks (2006)
9) Turfgrass Resource Center. (2008)

The primary purpose of Table 2.1 is to show the breadth of equipment that has been suggested for both field types. The inclusion of any item is not meant to suggest that it is a necessary item for the maintenance of a field. The next section will be dedicated to identifying which of these accessories are needed for the specific maintenance requirements of each field type. The premises upon which an inventory of equipment and supplies will be created is that it should: 1) be as comprehensive as possible; 2) identify items that are needed at a regular frequency; 3) identify items that are of environmental or financial consequence; 4) highlight the differences in requirements between the two field types.

Without financial constraints, the accessories that can be purchased to care for a field are virtually limitless. Therefore, some practicality must be employed to limit this analysis to the items and practices that are required to secure the health of the field, and thereby increasing its longevity. In addition, it is assumed that beyond what is identified, supplementary items will be needed to deal with unforeseeable circumstances. However, these instances will not be accounted for because they cannot be predicted to occur at any regular interval - or at all. Also, precautions can often be taken by turf managers to help minimize the risks and impacts of such occurrences that would require additional maintenance needs.

Table 2.2 below outlines the items deemed necessary for the maintenance for artificial and natural turfs. Also included is a discussion of the rational for the inclusion of any given items. Much of the equipment needed is necessary for both field types. Where differences in the equipment needs do occur between the two fields, it is generally because natural grass requires maintenance practices that artificial turfs do not (e.g. such as mowing, fertilization, and aeration) to keep them healthy.

Table 2.2: Equipment and Supplies Recommended for the Maintenance of Fields		
Maintenance Equipment & Supplies		**Discussion**
Synthetic	**Natural**	
Tractor/utility cart	**Tractor/utility cart**	A tractor or utility vehicle is useful for maintenance, and is often used as the primary machinery to which other equipment is attached.
Assorted hand tools	**Assorted hand tools**	Hand tools are the easiest way to ensure quick fixes to problematic spots in the field.
Broom, brush or tine		The regular dragging of a synthetic field is a key to the maintenance of its fibers. Similarly, drag brushes are useful to evenly spread infill. Equipment, such as a brush, broom, or tine is needed to carry out these tasks.
Sweepers/blowers	**Sweepers/blowers**	A sweeper or blower ensures the proper removal of debris for optimal play quality. While the accumulation of organic debris is more problematic on synthetic fields, inorganic debris is equally problematic for both turf types.
Roller		Frequent rolling is recommended to keep synthetic fibers from standing up and forming a grain.
	Mower	Blades of natural grass must be trimmed to ensure proper play quality. A mower is a necessary piece of equipment to keep blades at the appropriate length.
Top dressing	**Top dressing**	Top dressing for natural and synthetic fields is occasionally necessary, as soil and infill can be lost or displaced. On natural fields, topdressing promotes stronger root systems, a more resilient surface, and improved playing surfaces. On synthetic fields, infill and sand must be added when these materials get displaced.
	Fertilizer	Fertilizer is applied to most natural fields to ensure the growth of a robust and deep rooted field.
	Aerator	It is recommended that a lawn be aerated once or twice a year. Aeration needs depend on the presence of problematic elements (e.g. thatches), and the degree of soil compaction.
Spraying equipment	**Spraying equipment**	Spraying equipment serves a very particular purpose (i.e. liquid cannot be applied by hand with a shovel). Each field type requires the application of numerous liquids. For natural fields it is used to apply agrochemicals such as weed control and pest control. For synthetic turf it is used for cleaning, wetting, and static control of the surface.
Water	**Water**	Water is necessary for the survival of natural turf. In addition, synthetic turfs are often watered down to control temperatures, lubricate the surface, and stabilize infill and reduce migration.
Irrigation system	**Irrigation system**	In order to apply water, a method of irrigation is necessary.
	Seed/sod	One of the primary benefits of artificial turf is the infrequency with which it must be replaced. Thus, to fully consider the potential of artificial turf, the impacts of seed and sod replacement should be taken into account. Many lawns will benefit from a scattering of grass seed after top dressing and this will thicken the grass for the next year creating a dense healthy green lawn.
	Paint	For natural grass, field lines must be painted on. Also, these lines must be re-painted after as the painted lines are grown out and mowed away. For artificial fields, paint is used to make temporary lines when the field is used for diverse purposes. Permanent lines can be laid into the system, or can be painted on with fairly infrequent re-application.

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In considerations of turf maintenance, the majority of the equipment suggested by the various authors was not deemed necessary for field maintenance or consequential to maintenance evaluations. Several items were excluded because they are needed relatively infrequently or on a circumstantial basis. For day to day upkeep, the needed equipment is fairly evident. However, for items that might only be used on an occasional basis or that serve to alleviate the build of long term problems, their necessity is highly subjective. Often, such items can be rented, or a contractor can be hired to do the job that the equipment is meant to serve. As such, the capital investment and storage required of these items may not be prudent. Examples of equipment used fairly irregularly are: field magnet, vacuum, and pressure washers or flushing equipment. Supplies that are used in small enough quantities in the long run to render any associated impacts negligible are: chemical disinfectants and liquids to minimize static on artificial turf. Similarly, on natural fields, pesticides should only be applied when needed, and are not recommend for application at regular intervals as a preventative measure. Bruneau et al. (2001) of North Carolina State University's Center for Turfgrass Environmental Research & Education notes that when a field is properly maintained, insects are seldom a problem.

Some of the suggested items that were disregarded serve very real field needs. However, in several cases, these needs can also be served by other equipment or additional labor. This is the case for devices such as spiking equipment, a groove or silt seeder, a core harvester, top dressing equipment, and a seed and fertilizer spreader. Other equipment is only needed in certain circumstances, which may not necessarily occur for any given field. For example, the need for painters, mechanical scrubbers, and rubber blades to plow snow and de-thatching equipment will vary from field to field.

Supply Use Rates

Equipment that is needed for maintenance will only have to be purchased a few times over the life time of a turf. On the other hand, supplies must be acquired at regular intervals. Quantities and associated impacts for any given supply can vary greatly. For a true comparison of turf requirements, the rate of use for each of these supplies will be evaluated below.

Fertilizer

Fertilizer requirements are determined primarily by the type of grass, climate conditions, and the percentage of nitrogen that a fertilizer contains. There is a slight variation in the suggested amounts of nitrogen per year. Multiple applications are usually necessary, as fertilizer can damage a field if applied in quantities greater than one pound of nitrogen per one thousand square feet. Pettinelli (2007) of the University of Connecticut suggests two to three pound of nitrogen per thousand square feet, depending on whether clippings are left on the field. Similarly, Johnson et al. (2002) suggests two to four pounds per thousand square feet. Reicher and Throssell recommend fertilizing 0.75-1.5 pounds per thousand square feet four times a year. For this study, we will assume a fertilization rate of three pounds of nitrogen per thousand square feet, broken up into two applications. Based on our assumptions, 225 pound of nitrogen should be applied to an 85,000 square foot field annually.

Water

The precise amount of water required for a natural field can vary dramatically. Irrigation needs will differ based on the climate the turf is located in: humidity, precipitation, and the

temperature all play a role in determining the amount of moisture that must be added to a field. The condition of a natural field will also figure into its irrigation needs. Minimum levels of maintenance prevent the creation of problems such as thatches, which can impede water from reaching the soil. If systems are not kept in working order, the efficiency of irrigation will be compromised. Lastly, the way in which irrigation is carried out can change the amount of water needed. Demand on fresh water will change based on the time of day irrigation takes place (due to evaporation), and if alternative sources can be utilized. All of these factors can result in more or less water needed to achieve a static level of moisture. Duble (1993) provides a range of 12 to 36 gallons per square foot needed in Texas, depending on the irrigation needs for different regions. The Sonoma County Water Agency (2009) uses 22.5 gallons per square foot when watering city lawns.

Topdressing

Topdressing is the addition of sand, soil, compost, or other material to the turf surface. It serves to level the playing surface, promote stronger root systems, and create a more resilient surface. This is accomplished by the added material promoting the decomposition of the organic matter that is between the soil surface and the grass blades.

Generally the application of topdressing should be done following fertilization, especially in the spring. Chirillo (2008) notes that some fields might call for 2 to 3 applications per year. The Sports Turf Managers Association (2009) cites five applications per year for a sand based soccer field. For our purposes one application per year should be accounted for, while we acknowledge that additional applications may be necessary.

Rolawn (2010), a European supplier of topsoil and producer of cultivated turf, suggests that based on the time of year different quantities of topdressing be applied. They recommend that 1.5 liters of topsoil per square meter be applied in the summer, and twice that amount be applied in the spring and autumn.

For synthetic fields, topdressing consists of the addition of crumb rubber infill. Additional infill may be periodically necessary, as over time large quantities can be displaced. The Sports Turf Managers Association (2009) gives an estimated application rate of 10 tons of dressing, applied once during the year.

Paint

Field markings must be repainted on occasion to maintain the field's usefulness for various sports. Hall (2004), of TruMark Athletic Field Marker, notes that five gallons of diluted acrylic latex paint will cover 1,000 linear feet that is four inches wide. He also estimates that a standard football field requires 4,600 linear feet of paint to apply four sets of hash marks, and five yard lines. This equates to around 25 gallons of paint that is needed, according to his approximations. However, for a NCAA Division I Football game, he calculates paint needs for basic lines are 60% higher, with 27.5 gallons necessary for out of bounds lines, and 12.5 gallons for yard lines. In addition, in this instance 55 gallons of colored paint was also used.

Hall's (2004) figure may be a bit high when compared to the recommendations of others. The Sports Turf Managers Association (2007) suggests that for a regulation size football field seven and a half gallons of paint are needed for the hashes and field numbers. This figure is five

gallons less than Hall's calculation. In another publication, the Sports Turf Managers Association (Natural Grass Athletic Fields 2009) suggests that for an 114,000 square foot sand based soccer field, around 100 gallons of paint are needed for 6 applications annually. Meanwhile, a provider of aerosol paint, the California Field Supply Company (2007), offers an even more conservative figure. They estimate that 3.36 gallons of aerosol paint is needed for the initial layout of the field—which must be reapplied a second time per year—and 1.68 gallons are needed for weekly over markings in a 30 week year (or half of that for lower volume fields). Although the California Field Supply Company does not indicate the size and purpose of the field they are considering, only indicating that it was a field of "standard dimensions."

The amount of paint required for an application of field markings becomes even more muddled when considering the actual materials that go into the painting of Florida State University's Football Field. Theacc.com (2005) estimates that 460 gallons of paint are applied to the field prior to each game. They note that approximately 100 gallons is used to apply white lines, numbers and hash marks. An additional 360 gallons is used on the sidelines, and to paint the team emblem midfield and in the end zones.

The amount of paint needed per application is difficult to determine, given the broad range of estimates suggested. However, the slight differences in the amount and type of paint needed for natural and synthetic fields are insignificant when comparing the number of applications required. Since natural grass is mowed frequently to maintain its proper length as it grows, lines must be reapplied at regular intervals. Most literature seems to suggest that paint should be reapplied to grass prior to each event. On the other hand, a synthetic turf needs far fewer applications of paint. In fact, the Sports Turf Managers Association (Natural Grass Athletic Fields 2009) only accounts for two applications per year on artificial fields. However, a field manager may choose to apply paint more frequently to meet more rigorous aesthetic needs.

Replacement Seed and Sod

It is assumed that over time natural grass will get old and need to be replaced. With that, new seed or sod will be required once the old turf is removed. The frequency with which this is expected to occur can also affect the costs and life cycle of the field. Another practice that consumes an excess of seeds is over seeding. Over seeding is done to make the surface greener in the winter, and to support sports that go later into the season (i.e. that are played late into the winter or in the spring). However, this practice is not recommended for general maintenance, as it can compromise the health of the existing grass that must compete with the additional seed grass variety.

2.5 Cost

In this section the cost of natural and synthetic fields will be explored for comparison. Estimates will be based on a sample field of 85,000 square feet. This field size is large enough for a regulation size American Football (57,600 sq. ft.) or International Soccer (69,300 sq. ft.) field plus side lines.

2.5.1 Installation Costs

The cost of turf construction varies dramatically based on numerous factors. As to be expected, the needs requirements for a field determine its associated cost. The size and type of play that will occur are the principle considerations when calculating construction

costs. The drainage and irrigation systems necessary to suit the capacity of any particular field also must be taken into account when gauging expenses. The location of a field installation also factors into its total price, determining its costs related to labor and the difficulty of installation based on factors like soil and climate. For example, additional costs may result from the labor necessary to prepare a difficult surface or to offset weather-related delays in the construction schedule.

The construction price for a natural field can span a wide range depending on the properties of the land it is built on. If native soils are very sandy, they can support the installation of new turf without additional materials to improve the surface stability. Native soil fields are the least expensive of all natural fields. Of native soil fields, there are two options: seeding and sod. Seeding is the less expensive option, because it does not require the purchasing of sod or top soil. This option runs at about $1.20 per square foot. (Sports Turf Managers Association, 2008; Turfgrass Resource Center, 2008). Sod, on the other hand, costs about $2.25-$5.25 per square foot (Sports Turf Managers Association, 2008). Other types of natural turf require the addition of sand, and possibly other materials, to improve the robustness of the root zone for greater availability. The Turfgrass Resource Center estimates that basic sand-based field installations cost between $2.94 and $4.12 per square foot. However, they note that more elaborate sand-based systems can cost over $7 per square foot to install. Meanwhile, the Sports Turf Managers Association estimates the average cost of construction for sand based systems as $5.25 for a sand cap and $8.50 for a sand and drainage. Using these figures, estimates for a sample 85,000 square foot field are calculated in Table 2.3 below:

Table 2.3: Installation Cost for a 85k Square Foot Grass Field

Natural Field Type	Cost
Seed	$102,000
Sod	$191,250 - $446,250
Basic Sand	$250,000 - $350,000
High-End Sand	$722,500

Meanwhile, the cost of a synthetic turf varies based on many of the same aspects as natural turf. The existing condition of the field affects the cost of surface preparation, including: excavating the site, adding any necessary foundational materials, and compacting the foundation. The more material that must be removed, the greater the cost of installation will be. A proper drainage system is critical for artificial fields; without it, damage typically occurs from moisture that is trapped in the turf components. This is true even of indoor turfs, as liquids are often applied to clean and maintain their surface. Choices of turf components also influence price, including: the quality of fibers, padding, backing, and infill. In addition, specialized logos or sports lines have associated costs based on whether they are painted or sewn in. The price range of synthetic turf per square foot is $6 to $11.76. The Sports Turf Managers Association (2008) estimates that the construction cost for a synthetic turf runs between $6.50 to $11 per square foot. The Turfgrass Resource Center (2008) approximates installations to be on the higher end from $10 to $11.76 per square foot. Meanwhile, Sporturf, a synthetic turf provider, estimates that installing an artificial turf field costs from $6 to $8 per square foot. However, they also note that a

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10,000 square foot "state-of-the-art fake grass" turf was installed in Shaw Park, GA for $30,000 (a price of $3 per square foot). Using these figures, the cost of an 85,000 square foot synthetic turf field ranges from $510,000 to $999,600. This figure is significantly higher than the range of $102,000 to $722,500 found for natural fields.

Comparisons of the costs to install natural and artificial fields in other studies show similar differences in price between the two field types. Several case studies provide estimates of the installation costs for the two types of fields without noting the size of the field. Despite this omission, these works provide insight into the potential construction costs of fields, as well as the difference in costs between synthetic and natural turfs. The price estimates from these various works are listed in Table 2.4. Of note is the minimum of all of these costs for natural fields, which has been estimated to be about half of the cost calculated above, at $50,000. Meanwhile, the prices quoted for synthetic turfs are on the higher end of the range found earlier. Furthermore, our calculations show synthetic field installations as costing from 0.7 to 9.8 times more than a natural field. Several of the additional studies show artificial fields as ranging from twice the cost of grass to 20 times the cost.

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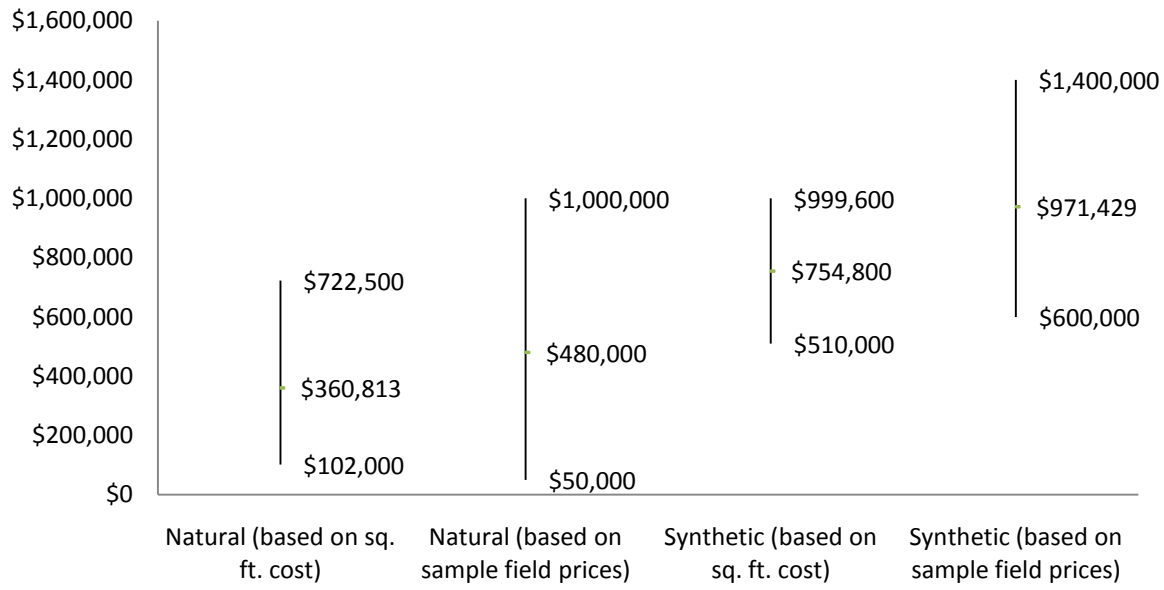
Table 2.4: Price Estimates for the Total Costs of Installation for Natural and Synthetic Fields				
Resource	**Context of Research**	**Synthetic**	**Natural**	**Number Of Times Greater Cost Of Synthetic Turf Installation as Compared To Natural Turf**
Turfgrass Resource Center (2008)	A publication that addresses concerns about synthetic turf using scientifically backed data for a non-profit trade association that represents the turfgrass sod industry.	$850,000 – $1,000,000	$50,000 – $600,000	1.4 to 20
Williams and Pulley (2002)	An investigation conducted at Brigham Young University for their football field, half of which is synthetic, and the other half which is sand-based natural field.	n/a	n/a	11.8
Powell (2005)	A conference presentation aimed at athletic field managers addressing the complexities of natural and synthetic turf. Powell is a turfgrass agronomist with the University of Kentucky.	*Basic:* $600,000 *High End:* $1,000,000	*Soil:* $50,000 *Sand:* $1,000,000	0.9 to 18:1
Claudio (2008)	A journal article in *Environmental Health Perspectives (EHP)*, a monthly peer-reviewed research and news publication by the U.S. National Institute of Environmental Health Sciences, National Institutes of Health, Department of Health and Human Services.	$1,400,000	$690,000	2.0
Skindrud (2005)	A case study for a installation at Springfield College in Springfield, Massachusetts, in an informational article comparing natural and synthetic fields for landscape contractors.	$800,000	$400,000	2

Using the information provided above, a precise estimate for the installation costs of different turf options will be determined for use in total system cost calculations. The range of comparative proposed prices can be seen graphically in Figure 2.1 below. This figure shows the minimum and maximum prices provided by various authors, as well as the mean price calculated for each proposed turf type. For our purposes, a single value is needed for a comparative analysis of the total cost of synthetic and natural turf systems. For this objective, the price per unit (i.e. per square foot) value is a more credible estimate because: 1) it is known to be a comparison of two fields of equivalent size, and 2) it is scalable by a known factor to achieve a specific case study field size. It should be noted

that, regardless of whether the price per square foot or total price is used, the average cost for a synthetic field is twice that of a natural field. Using the square foot cost, the mean value of the research investigated will be used for cost calculations. Specifically, this is $8.88 per square foot of synthetic turf and $4.24 per square foot of natural turf, or $754,800 and $360,813 respectively for an 85,000 square foot field.

Figure 2.1: Initial Cost of Various Turfs



2.5.2 Equipment Costs

Equipment costs are calculated in large part by the equipment and supplies identified in the maintenance section of this report (see Section 2.4: Maintenance). The average cost associated with each of the identified items has been collected from various studies. These prices have been listed in Table 2.5 below. These estimates will be used to calculate the capital costs of maintenance.

Table 2.5: Suggested Cost for Equipment Based on Field Type		
Equipment:	**Synthetic**	**Natural**
Tractor/Utility Cart	$7,000 to $16,000 (a) $2,500 to $16,000 (b)	$7,000 to $18,500 (a)
Assorted Hand Tools	No cost estimate given	No cost estimate given
Sweepers/Blowers	$1,500 to 20,000 (a) $1,500 (c) $1,500 to $20,000 (b)	No cost estimate given
Broom, Brush Or Tine	$500-3,000 (a) $500 (c) $500 to $3,000 (b)	
Roller	$250 to $2,000 (a) $250 to $2,000 (b)	
Mower		$13,000 to $69,000 (a) $107* (d)
Spraying equipment	$1,000 to $35,000 (a) $1,000 to $35,000 (c)	No cost estimate given
Aerator		$3,500 to 17,000 (a)

*yearly cost for a five year lifetime

References for Table 2.5

a) Turfgrass Resource Center(2008)
b) "Synthetic Turf Maintenance Equipment" (Brakeman 2005)
c) "2004-2005 Maintenance Budget Synthetic Infill Field" (Brakeman 2005)
d) New Yorkers for Parks (2006)

The range of estimated prices given by any author can be quite large. For instance, spraying equipment is expected to run somewhere between $1000 and $35,000 (Brakeman, 2005). The equipment that is needed for the maintenance of both field types is assumed to be similar in price. These items—tractor/utility carts, hand tools, sweeper/blowers, and spraying equipment—are similar enough that for the purposes of estimations, they do not need to be differentiated , despite possible differences in the specific devices. In general, cost estimates will be made for equipment using the mean of prices provided. Where this is not the case, this will be noted. The specific price estimates that will be used are:

- A tractor/utility cart will be assumed to be around $10,375, the mean value of all suggested figures that range from $2,500 to $16,000.
- No estimates were given for the total price of hand tools. However, it is assumed that the cost of these is inconsequential in the comparative costs of artificial and natural fields. Therefore, these costs will not be included.
- The cost of a sweeper/blower will be assumed to be $7,667. The suggested prices range from $1,500 to $20,000.

- Some combination of a boom, brush, or twine will be assumed to be $1,333.
- A roller will be assumed to be $1,125, the mean value of all suggested figures that range from $250 to $2,000.
- It will be assumed that a quality mower will be needed given the frequency with which it will be used. The estimate given by New Yorkers for Parks (2006) will be disregarded, as it is questionable that the type of mower needed can be obtained for such a figure (i.e. $107 per year for five years). The midpoint price of $41,000 will be used in calculations.
- Spraying equipment is assumed to be $18,000.
- The suggested price for an aerator is $3,500 to $17,000. The mean of this, or $10,250, will be used in calculations.

Using these figures, the total equipment cost will be $38,500 for a synthetic field and $87,292 for a grass field.

2.5.3 Total Cost of Ownership

The table below provides examples of a 10-year total cost of ownership, comparing the cost to install and maintain natural sod turf versus synthetic turf. The example uses a 78,000 square foot field, private stadium.

Table 2.6: Total Cost of Ownership

	Artificial Turf	Sod
Installation Cost	$692,640	$330,720
Year 1 Costs	14,900	65,258
Year 2 Costs	14,900	65,258
Year 3 Costs	14,900	65,258
Year 4 Costs	14,900	65,258
Year 5 Costs	14,900	65,258
Year 6 Costs	14,900	65,258
Year 7 Costs	14,900	65,258
Year 8 Costs	14,900	65,258
Year 9 Costs	14,900	65,258
Year 10 Costs	14,900	65,258
10-Year Life cycle Cost	**$841,640**	**$ 983,300**
Uses during 10-Year Cycle	1,400	350
Cost per use	$ 601.17	$ 2,809.43

Key Assumptions:

Artificial turf cost of $8.88 per sq ft, $4.24 for natural turf (sod)
Includes general maintenance, equipment, and water costs (annualized average amounts)
Assumes field does not already consist of natural grass
Does not include "replacement" costs, which may or may not occur during mid-point of life of installation

2.6 Risk of Injury

One of the primary concerns for organizations considering the implementation of synthetic turf is whether it poses any significant health or injury risks. Numerous studies have been conducted assessing the likelihood of injury on natural grass and synthetic turf. Some studies reveal that there is very little difference in the rate, type, severity, or cause of injuries obtained on natural grass or synthetic turf (Fuller et al. 2007a, 2007b). A more recent study by Meyers (2010) shows that the latest generation of synthetic surface, FieldTurf, is safer to play on than natural grass fields. Through the analysis of the various injuries that occurred over the course of 465 collegiate games, Meyers shows that FieldTurf has lower incidence of: total injuries, minor injuries (0-6 days lost), substantial injuries (7-21days lost), and severe injuries (22 or more days lost). FieldTurf also had significantly lower injury rates that natural turf when comparing across play or event type, grade of injury, or various field conditions and temperatures. In addition, there was no significant difference found in head, knee, or shoulder trauma between the two playing surfaces.

Meyers' (2010) research is the most comprehensive study to date, and it addresses previous inconsistencies in findings on injury patterns. Prior studies on injuries suggest that rates for the two surfaces are similar, but that the type of injury varies (Meyers and Barnhill 2004; Steffen et al. 2007). Furthermore, there was no consensus amongst researchers on the difference in type and severity of injuries. Meyers and Barnhill (2004) found that injuries on natural turf tend to be more severe, with greater incidence of head concussions and ligament tears. Steffen et. al (2007), however, found that injuries on synthetic turf tend to be more long-term but occur at a lower rate than injuries on natural turf. Given this conflicting evidence, no major conclusions could be drawn about differences in risk levels between the two fields before the publication of Meyers' work.

The following section will discuss the specific health and injury risks posed by: surface hardness and traction, rates of abrasion, risk of staff infection, heat-related stress and injuries, and material safety.

2.6.1 Traction

Forces that resist shoe-surface motion have been termed traction forces, as they do not always obey the classical laws of friction (Shorten et al., 2003). If traction forces are too high, foot fixation may occur, placing a great deal of stress on lower extremity ligaments during movement (Shorten et al., 2003). This can result in an increased rate of knee injuries and collisions (Pasanen et al. 2007b). Several authors have noted that surface to shoe traction is correlated with increased incidence of injury (Pasanen et al. 2007A; Powell and Schootman 1992; Orchard and Powell 2003). Orchard and Powell show that cold weather reduced traction, leading to a lower injury rate, supporting the claim that traction plays a role in increased risk.

Research clearly points to a correlation between increased traction and greater rates of injury. Several researchers have noted that the more consistent, compliant surface that artificial turf offers is associated with lower shoe-surface traction (Noyes 1988; Schootman 1994). Meyers (2010) notes a lower incidence of injuries attributed to shoe-surface interaction during contact with synthetic turfs over natural grass turfs. In addition, Meyers

attributes the lower incidence of ligament sprains on FieldTurf found by Ekstrand, Timpka, and Hagglund (2006) to the possibility of lower shoe-surface traction.

2.6.2 Hardness

Increased hardness is correlated with increased likelihood of severe head trauma. However, the hardness levels of synthetic fields, if set up correctly, fall well below these dangerous levels (McNitt and Petrunak, 2007c). Furthermore, it is easier to maintain an existing level of hardness on synthetic fields because hardness is related to infill depth. On the other hand, the hardness of natural fields varies according to soil-moisture, which is more labor-intensive to manipulate on an ongoing basis.

However, the solution is not to make fields as soft as possible. A surface that is not at the correct hardness level will affect athletes' performance, particularly by bringing on early onset of leg muscle fatigue (New York City Department of Health and Mental Hygiene, 2008). Set up should be carefully carried out to ensure proper hardness levels.

2.6.3 Abrasion

One of the major criticisms about synthetic turf is that it is seen by many to be more abrasive than natural turf. The old versions of synthetic turf elicited public complaint about incidence of abrasion (New York City Department of Health and Mental Hygiene, 2008). However, the newer versions have longer and softer fibers, making them less abrasive. At Penn State's Department of Crop and Soil Sciences, a study on synthetic turf systems included a measurement of the abrasiveness of the surface by pulling foam blocks over the turf's surface (ASTM Method F1015). The results, reported by McNitt and Petrunak (2007a), states that infill systems are less abrasive than older carpet-like turf generations. The abrasiveness was also affected by the grooming of the field surface (McNitt and Petrunak, 2007a).

Comparisons of the impacts of abrasions between natural and synthetic turfs are slightly favorable towards artificial fields. Unfortunately, the abrasiveness of natural fields has not been measured for contrast, as the ASTM Method F1015 is only applicable to synthetic surfaces. However, Meyers (2010) found that the rate of epidermal injuries caused by interaction with the surface were slightly lower on artificial turfs (1%) than on natural grass (1.3%). This research investigates some of the irregular injury patterns initially observed on artificial turf (Meyers and Barnhill, 2004). In this preliminary study, abrasion occurs more frequently on synthetic turf than natural turf (Meyers and Barnhill, 2004).

It should be noted that in and of themselves, abrasions are not usually severe injuries. However, these types of injuries can lead to more severe complications, including staph infections.

2.6.4 Staph Infections

Concerns have been expressed about the role that synthetic turf plays in facilitating staph infections. Methicillin-resistant Staphylococcus aureus (MRSA) is a drug-resistant bacterium that can result in severe, and sometimes fatal, infections. Due to increased outbreaks of MRSA in athletes, concerns have developed about whether turf fields increase

the risk of such infections. While research suggests that abrasions from injury may play a role in the contraction of such infections, there has been no evidence of a causal relationship between synthetic turf and staph infections.

There are a variety of studies about the role that synthetic turf plays in the contraction of MRSA. All research indicates that synthetic turf is not a cause of MRSA. However, several authors point out that abrasions caused by turf may provide a means of entry for the outbreak of infection (Kazakova et al. 2005; The New York City Department of Health and Mental Hygiene 2008; McNitt 2008). The New York City Department of Health and Mental Hygiene claims that other factors are the primary cause of bacterial infections. Begier et al. (2004) reached similar conclusions, despite noting a seven-fold increase in the risk of MRSA contraction for athletes with turf burns. They concluded that it is not possible to assess the risk of outbreak associated with the playing surface because all players used artificial turf, and other factors, such as use of a poorly maintained whirlpool, which played a role in MRSA contraction. Furthermore, The New York City Department of Health and Mental Hygiene (2008) dismisses the associations that Begier et al. (2004) and Kazakova et al. (2005) make between synthetic turf and MRSA, because they did not compare them with abrasions caused by different sources. McNitt, Petrunak D, and Serensits (2008) determined that synthetic turf—and fields in general—do not provide an environment that is hospitable for hosting bacteria.

While infections may be associated with abrasions, not all abrasions result in MRSA. In addition, cases of MRSA have occurred in individuals who have not generally had contact with synthetic turf, such as dancers, wrestlers, fencers, and non-athletes. Furthermore, given that turf surfaces themselves do not harbor such bacteria, it is doubtful that there is an increased risk associated with abrasions that originate from synthetic turf surfaces over abrasions from other surfaces (McNitt, Petrunak D, and Serensits, 2008). However, since abrasions provide a means of entry for staph infections, rates of abrasion can be important to bear in mind (see the section on abrasion injuries).

Behavioral factors play a far greater role in determining whether staff infections will develop, including: the covering of wounds, physical contact with other players, and hygiene practices (McNitt 2008; Benjamin, Nikore, and Takagishi 2007; Nguyen, Mascola, and Bancroft 2005; Kazakova et al. 2005; Begier et al. 2004; Srinivasan and Kazakova 2004; Tobin-D'Angelo et al. 2003; Stacey et al. 1998).

2.6.5 Heat

There are two major concerns about the affect of heat on synthetic turf. The first is the material toxicity that can result from increased temperatures, a concern that will be discussed in the material safety section that follows. The second is the heat-related stress that can be caused by increased temperatures, such as heat exhaustion, heatstroke, burns, and blisters. We will examine these problems here.

Temperatures of synthetic turf do get higher than the surrounding air (see section on all-weather availability), which can play a factor in heat-related stress. There are two studies indicating that synthetic turf has resulted in heat blisters on players' feet (Williams and

Pulley, 2002; SI.com, 2007). However, behaviors play a more significant role in creating heat-related injuries, such as: reducing playtime and preventing dehydration (Anderson et al., 2000; New York City Department of Health and Mental Hygiene, 2008b). It has also been suggested that humidity plays a greater role in heat stress than temperature (New York City Department of Health and Mental Hygiene, 2008b).

As can be seen, there are a variety of concerns about the safety of synthetic turf for players. Evaluation of these concerns finds that these risks, in many instances, can be mitigated. There are some risks that people should be aware of, but there is no evidence that the dangers of synthetic turf greatly outweigh those of natural fields.

2.6.6 Injury Conclusions

Despite these findings which are generally favorable towards synthetic turf, there is still a strong public perception that it is more likely than natural turf to cause injury. A study shows that 91.2 percent of NFL players thought that artificial turf would be more likely to contribute to injury (NFL Association, 2004). However, this public perception could be rooted in a variety of factors beyond the grasp of science. Players may be used to other fields or associate new technologies with their earlier, less-developed versions.

2.7 Material Safety

The use of athletic fields made of recycled tires has also been called into question because of concerns regarding toxicity. For example, the state of New York has recommended a moratorium on future construction of such fields pending additional research. Authorities are worried that because of the chemical content of the material, exposure by various means could endanger the health of field users, especially children. However, extensive research has pointed to the conclusion that these fields result in little, if any, exposure to toxic substances.

On the face of it, concerns about the toxicity of crumb rubber fields is quite warranted. The raw material from which they are made – used car tires – is known to contain numerous toxic and potentially carcinogenic compounds. These chemicals include polynuclear aromatic hydrocarbons (PAHs), phthalates, volatile organic compounds (VOCs), zinc, iron, manganese, nickel, PCB, copper, mercury, lead, cadmium, volatile nitrosamines, benzothiazole, isononylphenol, and more.

These chemicals are of concern for various reasons. Many of the metals have been associated with damage to the nervous system, as well as irritation of the eyes, nose, and throat. PAHs have been identified as a cancer risk and as causing substantial organ damage. And VOCs have been implicated in causing organ damage, or symptoms of lesser consequence such as nausea, headaches, and sense organ irritation.

However, the mere presence of a substance is not necessarily cause for concern. For the most part, when these chemicals are present in tires, they occur in very small concentrations. Also, their presence does not automatically equal exposure. Tires are relatively, though not entirely, inert, and the vulcanization process that they undergo to prepare them for their second life as artificial turf, renders them more, rather than less, stable. Further, many of the chemicals of concern are already present at relatively high levels in urban environments, as a result of

numerous human activities which are not presently considered controversial: driving, heating and cooling systems, and regular production of household and industrial waste. Even the consumption of certain foods has been noted to raise a person's exposure to substances such as PAHs (van Rooij and Jongeneelen, 2010).The primary issue is not whether artificial turf contains such materials, for this is undoubtedly true, but, whether there is sufficient human exposure to elevate the risk above accepted levels. While small increases in risk may not be insignificant, a generally accepted measure of danger should be adopted, namely the general scientific consensus in determining whether an elevated level of risk ought to be deemed significant.

Being in proximity to a substance is not in itself a risk. There needs to be a means through which one's body comes into contact with the substance – a path of exposure, if you will. For crumb rubber, as it is not radioactive, there are numerous possible paths of exposure through which a human could conceivably be subjected to potentially noxious chemicals. The first and most direct route of exposure would be through actual oral ingestion of pieces of the crumb rubber itself. Now, it is highly unlikely that most field users will decide to consume a chunk of the playing field. However, this is a valid concern when considering the most vulnerable portion of the population – very small children. It is entirely possible, and perhaps inevitable, that some small children will pick up infill pieces and swallow them.

Secondly, and more likely, would be hand-to-mouth exposure, especially of dust or small particles of crumb-rubber. If such matter got on the hands of a user of the field, and the user then touched his hand to his mouth, he could ingest infinitesimal amounts of crumb rubber particulate.

Thirdly, dermal exposure is highly likely. The skin of field users is bound to come into contact with the field's surface. Given the naturally protective qualities of skin, this is an unlikely route of exposure, unless the substance is abrasive to skin itself.

Fourth, there is concern about chemicals leaching off of the fields – especially if the fields are outdoors and subjected to periodic rainstorms (Moretto, 2007). Such chemicals, if water-soluble, could come to enter the groundwater or drinking water supply.

Finally, and perhaps most significantly, there is the possibility of inhalation of toxins from the field. Such inhalation would generally come about through one of two possible phenomena. The first is a process known as "out-gassing" or off-gassing." As noted above, recycled tires are substantially, though not entirely, inert. Some compounds within the material will, over time, come to be released from the material and to enter the air. This is a particular concern with so-called "volatile organic compounds," but also with PAHs. Secondly, repeated use of the field could cause atomized particles of the field to be produced as barely noticeable dust, or "particulate". Such particulate could be inhaled by users of the field.

The potential of toxic exposure along each of these pathways has been the subject of repeated inquiry. Numerous governmental agencies have carried out independent research into the toxic potential of crumb rubber, and we will review the results of this below. Generally, it has been found that crumb rubber fields do not present an elevated risk to health through exposure to

toxic substances, but researchers have noted some areas of concern. More typically, though, they have noted the present existence of "knowledge gaps"; a lack of full understanding at the general theoretical level which renders the inquiries to some degree inconclusive.

2.7.1 Direct Ingestion

Two major studies of the potential for toxic transference through direct ingestion have been carried out. The first, by Birkholz, Beton and Guidotti (2003), involved immersing tire particulate in chemical solvent and testing the resulting chemical for increases in carcinogens. This test did not clearly demonstrate a significant increase in carcinogenic levels.

A similar study, by the California Integrated Waste Management Board (CIWMB, 2007), subjected 10mg of tire shred samples to a chemical environment that replicated the human digestive system. In all, 22 chemicals were released by the samples, but none at levels that were associated with significantly elevated risk levels. Scientists performing this experiment were particularly concerned with an elevated risk of cancer in children. The study found, though, that ingestion of a significant quantity of tire shred did not elevate a child's risk of developing cancer, relative to the overall cancer rate of the population.

2.7.2 Hand-to-Mouth Contact

This same study, by the CIWMB (2007), also evaluated increased risks due to hand-to-mouth exposure. For hand-to-mouth exposure, researchers took wipe samples from field surfaces and were able to identify five chemicals present in rates significantly higher than the general environment. Calculations were then made to determine the frequency with which these chemicals would or could enter the body through hand-to-mouth contact. Though a high degree of variability and uncertainty was acknowledged, researchers found that, on average, the degree of toxic exposure due to hand-to-mouth contact would be well below acceptable levels.

Lead ingestion is a matter of concern with crumb rubber fields, for it is well-known that lead is used in tire production. However, one mitigating factor should be pointed out: tires do not contain uniform amounts of lead, and it is therefore possible to selectively choose particles from tires with low lead concentrations.

The New Jersey Department of Health and Senior Services (2008) carried out a study subjecting tire particulate to a simulated gastric environment. This was done to determine whether the amount of lead which could be absorbed by human beings as a result of casual ingestion through hand-to-mouth contact with crumb rubber dust would release significant quantities of lead. The findings were that the amount of lead released through gastric processes was not significantly different from that of ordinary soil samples. However, in certain types of fields, particularly those which used nylon fibers, elevated lead levels were observed.

A similar study was undertaken by the Consumer Product and Safety Commission (2008). The CPSC analyzed wipes taken from various crumb rubber fields and assessed the risk of exposure to minors who might be using these fields. It was determined that in no case

would exposure ever exceed chronic levels of ingestion of lead that could cause lead poisoning.

The Norwegian Building Research Institute's (2006) analysis of lead exposure similarly found that lead levels fell well within an acceptable range.

The US Center for Disease Control and Prevention (2008) has advised the careful selection of material for crumb-rubber fields. It is possible to select crumb rubber in which lead concentrations are low, and it is strongly advised that this be carried out.

PAHs are a source of concern for hand-to-mouth ingestion from artificial turf fields. The CIWMB (2007) investigated the possibility that four PAHs – such as the carcinogen chrysene—could be present at levels dangerous to humans. The study failed to show that this was the case.

2.7.3 Dermal Contact

In addition, PAHs have been studied for their risk associated with the dermal contact of crumb rubber. Such risks of PAH uptake have been determined as low amongst athletes (Hofstra 2007), based on certain assumptions regarding the circumstances of exposure and dermal bioavailability. Additional testing of real life exposure was conducted by Van Rooij and Jongeneelen (2010). Their study used biological monitoring (i.e. urine samples) to assess exposure. This method of assessment is advised when exposure can occur through multiple pathways, as is the case with PAHs. Their findings show that the uptake of PAH by athletes who have contact with crumb rubber synthetic turf is negligible. Additionally, diet and other environmental factors were identified as having the same level of PAH uptake as field exposure.

As far as dermal contact is concerned, the Norwegian Institute of Public Health and radium Hospital (2006) carried out an extensive analysis of possible health concerns. The only concern which they highlighted as potentially significant was the risk of allergic reaction to crumb rubber that contains latex, a well-known allergen. The study found, though, that there was no evidence to suggest that allergic reactions were caused by exposure to crumb rubber and speculated that latex in car tires was either "less available for uptake" or was "deactivated" as an allergen. The study acknowledges, however, the existence of knowledge gaps that make a full risk assessment in this particular area provisional.

2.7.4 Water Contamination

The question of whether chemicals will leach off of playing fields and enter the drinking or groundwater supply is of broader concern. Once again, the matter of whether or not such leaching ever takes place should not be the focus of concern. The question is: At what concentrations do chemicals leach off of fields, and will the natural environment be able to break down the chemicals at those concentrations?

Zinc is a metal of particular concern in this regard. Now, the simple presence of zinc is not necessarily problematic. Zinc is already present in significant concentrations in urban

environments, and is in fact essential to the metabolism of most plants and animals. However, zinc at high concentrations can be quite toxic.

Three studies have looked into the presence of zinc as a result of leaching from crumb-rubber athletic fields. The first, carried out by the Norwegian Building Research Institute (NBRI)(Plesser, 2004), was the most critical. It noted that the concentration of zinc in granulate particles exceeded the Norwegian Pollution Control Authority's guidelines for "most sensitive land use." However, it should be noted that Norway's standard for this particular pollutant is unusually stringent; the report noted that the same concentration is deemed by Canadian Water quality guidelines to be well within acceptable range.

California's Integrated Waste Management Board (2007) tested the concentrations of zinc leaching from crumb rubber fields. Its analysis seemed to indicate that the levels detected were not a significant health or environmental concern.

New Jersey's Department of Environmental Protection (2007) carried out a review of the safety of crumb rubber fields that took careful account of the presence of zinc in water leaching from these fields. They noted that a Dutch study from 2007 indicated that the amount of zinc that could leach into water supplies would not be injurious to human health. It would fall below the level of toxicity advised against by the World Health Organization. However, the same study noted that the amount of zinc potentially leached into groundwater exceeded limits set by New Jersey's own environmental standards.

The Swedish Chemicals Inspectorate (2006) has confirmed this finding, noting that zinc levels exceed what is acceptable in runoff, for it could damage ground-dwelling organisms. For this reason the Inspectorate advised against the construction of new crumb-rubber fields, but did not urge the elimination of existing fields.

The Norwegian Institute for Water Research (2005) has indicated that not only zinc, but also but alkylphenols, and octylphenol in particular, are also predicted to exceed the limits acceptable for environmental health.

Birkholz, Belton, and Guidotti (2003) performed toxicity tests on four different aquatic species using crumb-rubber leachate. They determined that undiluted samples produced a moderate risk to all four species, but that diluted samples did not. Noting that the likelihood of undiluted rainwater runoff was slim to entirely unlikely, they concluded that crumb rubber leachate does not pose a risk to aquatic species. However, it should be noted that they specifically looked at toxin levels of lauryl sulfate and sodium chloride. Zinc exposure was not tested.

2.7.5 Inhalation

A particular concern when it comes to the potential of inhalation of toxins from crumb rubber fields is Volatile Organic Compounds, or VOCs. As discussed above, VOCs have been implicated in causing organ damage, nervous system problems, and irritation of eyes, throat and airways.

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As pointed out by the New Jersey Department of Environmental Protection (2007), the likelihood of significant emission of VOCs from recycled tires is very low. This is because most VOCs would have already been emitted from tires while they were used for their original purpose of enabling automobile transit. The combination of frequently raised temperatures and long-term use would serve to eliminate most volatile gases from the material. Further, most tires spend up to a year in a scrap-yard between being discarded as tires and before being shredded for use in athletic fields. This additional year provides more opportunity for VOCs to be out-gassed. Studies serve to confirm these speculations.

The French National Institute for Industrial Environment and Risks (2007) carried out a study of the risk of exposure to VOCs from recycled tire athletic fields. The study found that the concentrations of VOCs emitted by such fields were low enough to not pose a risk to athletes using the fields, to officials, or to spectators.

The Norwegian Pollution Control Authority (2006) analyzed the levels of VOCs emitted from indoor fields to determine if a health hazard was indeed present. The finding was that, with adequate ventilation, these fields would not pose a health concern.

The New York City Department of Health and Mental Hygiene (2008b) commissioned a study of a number of the city's already-constructed athletic fields to determine if VOCs or metals were being out-gassed from the fields at significant levels. Though eight different VOCs were detected in the air, they were not at levels high enough to threaten human health. Additionally, it was not clear that the VOCs detected were indeed from the fields themselves, as there was no uniformity in the scores for the different fields, and VOCs were detected in control locations upwind from the sites.

The Norwegian Institute of Public Health and Radium Hospital (2006) analyzed the presence of VOCs emitted from fields and determined that there was no cause for concern. This includes the substance known as carbon black. Recent discussions have included the topic of carbon black, and the potential damage to the respiratory system. Carbon black is used in tires to provide the pigmentation, as well as to dissipate heat and maintain the shape (and life) of the tire. However, there have been no findings that carbon black in crumb rubber has been a serious health issue to users of playground surfacing. Similar research was performed by the California Integrated Waste Management Board in a subsequent, related study in 2007.

A preliminary test by the Connecticut Agricultural Experiment Station (Mattina et al., 2007.) showed that VOCs were indeed released from rubber pellets made from ground-up tires, the raw material for crumb rubber fields. Though the study noted that the levels of released VOCs did not appear to occur at a level clearly injurious to humans, further study was recommended.

The same study looked into the presence of volatile nitrosamines emitted by a sample of twenty different fields. Volatile nitrosamines are chemicals such as benzothiazole and 4-(tert-octyl) phenol. The study did not indicate that such chemicals were emitted at levels of

concern. A similar Dutch study looked into the levels of nitrosamines emitted from vulcanized crumb rubber and determined that such levels did not pose a risk to humans.

Both the Norwegian Building Research Institute (2006) and the California Integrated Waste Management Board (2007) have carried out tests of exposure to numerous potentially toxic metals present in tires, such as mercury, PCBs, nickel, cadmium, and chromium. Both studies identified levels that were either below detection limit or were at levels insignificant to health considerations. However, concerns were raised about levels of chemicals such as dibutylphthalate (DBP) and diisononylphthalate (DINP), whose presence can exceed EU standards.

2.7.6 Sample Testing

To investigate the issue of the content of lead and other metals in cryogenically produced crumb rubber, samples were sent out for laboratory evaluation. Materials were provided by a market leader, BAS Recycling of Moreno Valley, CA, from one of its primary customers, Environmental Molding Concepts (EMC). Synthetic field samples were sent to St. Louis Testing Laboratories, Incorporated, an independent third-party commercial testing laboratory, and analysis was conducted in February, 2009. Evaluations were carried out to ensure compliance with the U.S. Consumer Product Safety Improvement Act for Children's Products Containing Lead (i.e. CPSIA, Section 101), which places limits on the heavy metals content in children's product. The metals regulated by this act include: lead, antimony, arsenic, barium, cadmium, chromium, mercury, and selenium. Testing was done in accordance with American Standard Testing Method (ASTM) E1613, "Standard Test Method for Determination of Lead by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES), Flame Atomic Absorption Spectrometry (FAAS), or Graphite Furnace Atomic Absorption Spectrometry (GFAAS) Techniques."

In total, 40 tests were conducted, for each of the eight metals on five different color samples. Five colors (i.e. blue, green, rust, black, and gray) of turf were evaluated in order to account for possible variability of outcomes from different source contributions. All testing for lead indicated that sample contents were below problematic detection levels. For the remaining tests, all but one came back in compliance with regulation standards. In a single instance, the sample with blue colorization had slightly elevated levels of Barium. This test measured barium at 1228 ppm, which is 328 ppm above the limit. High levels of barium exposure can be troublesome. However, it should once again be noted that the mere presence of a substance is not necessarily cause for concern. It simply indicates a possibility of a risk of exposure. Further testing would be needed to measure the risk of contact. On the other hand, the absence of above limit concentrations precludes the possibility of exposure. In other words, a person cannot be at risk of exposure, if a substance is not present. As such, our testing found that the presence of lead—which was previously identified as being potentially problematic— does not pose a significant risk to people, and children in particular. In fact, the samples provided by BAS contained virtually no lead, at 20 parts per million, which surpasses the upper threshold limit of 400. Levels of lead even in soil are also acceptable at up to 400 parts per million, which signifies the insignificance of lead in the recycled rubber based material. Overall, cryogenically produced crumb rubber performed well against product safety standards.

2.7.7 Material Safety Conclusions

A review of existing literature points to the relative safety of crumb rubber fill playground and athletic field surfaces. Generally, these surfaces, though containing numerous elements potentially toxic to humans, do not provide the opportunity in ordinary circumstances for exposure at levels that are actually dangerous. Numerous studies have been carried out on this material and have addressed numerous different aspects of the issue. For the most part, the studies have vindicated defenders of crumb rubber, identifying it as a safe, cost-effective, and responsible use for tire rubber.

There remain a few objects of concern, though. First, the allergen potential of latex in tires used for athletic fields remains obscure. Though there has not been experimental confirmation of the risk of crumb rubber triggering a latex allergy, the possibility cannot be ruled out and needs to be investigated more thoroughly.

Second, lead exposure remains an object of some concern. The results of experimental evaluation of lead in these fields have been thus far inconclusive. Most studies have cleared the fields as safe in terms of lead risk, but others have noted an elevated presence of lead. Given the fact that lead levels in tires varies significantly according to production processes, it seems safe to conclude that given judicious selection of crumb rubber fill prior to constriction – that is, selection of material with low lead concentrations – lead exposure could be minimized significantly.

Finally, and most significantly, repeated testing has shown that the presence of zinc in leachate from crumb rubber fields remains problematically high. In many communities, these levels exceed what is allowable according to present environmental standards. Some studies have shown these levels to be acceptably low, and others have noted that certain governance areas – Canada's, for example – allow for higher levels of zinc in groundwater. However, generally speaking, it would appear that levels of zinc leaching into groundwater from crumb rubber fields are significant. Further research needs to be conducted into this question to determine whether it is a real concern, and if it is, greater innovation needs to be carried out at the level of product development to eliminate this concern. If this does not occur, the market for crumb rubber fields will be constricted to areas with relatively more relaxed groundwater-quality standards.

2.8 Environmental Impact

There are several issues that are encompassed in discussions of the environmental impact of a product or activity. Largely, these can be categorized into global warming impact, risks to human health (including toxicity), and disruption to ecosystems. The potential toxicity of synthetic turf, as well as its possible effects on human health was largely discussed in the previous sections (see Section 2.6: Injury, and 2.7: Material Safety). In addition, some of the aspects of ecological toxicity were also discussed in Section 2.7: Material Safety. The following section addresses additional environmental concerns related to natural and synthetic fields. The life cycle global warming impacts will be addressed specifically.

2.8.1 Environmental Concerns

Fertilizer

The environmental impact of fertilizers has garnered much attention in recent years, with growing concerns about bio-fuels. Fertilizers are made using very energy-intensive manufacturing processes to produce nitrogen. The basic feedstock for making nitrogen fertilizer is a petroleum product, natural gas. As a result, fertilizers can be the largest component of an agricultural product's energy consumption (Pimentel 1991; Shapouri et al., 1995; Pimentel 2002; Shapouri et al., 2002; Kim and Dale, 2004). With greater embodied energy, these products have a high global warming potential.

Given this, the amount of fertilizers needed for natural fields is an important environmental consideration. The global warming impact per pound of nitrogen in fertilizers has been shown to be 0.8 to 1.2 pounds of CO_2 (West 2002, Robertson 2000, Snyder 2007). Therefore, the carbon footprint associated with the fertilization of a natural turf field is between 204 and 306 pounds of CO_2 equivalent. This is between 0.092532 and 0.138799 tons.

Fuel Consumption

In assessments of global warming impacts, evaluations are often done by means of energy use as a proxy. While energy consumption alone does not account for all of the aspects of green house gas emissions, it is one of the major contributors of direct and indirect emissions. In an inventory of natural turf emissions, Townsend-Small and Czimczik (2010) find that the single greatest source of emissions is fuel use. For turf maintenance, fuel is used in transport, for mowing, and leaf blowing. Some of these emissions can be reduced by selecting electrically based machinery.

Grass grows quickly, and it must be mowed regularly to maintain optimal play quality. It is often assumed that such fields are cut on a weekly basis. Townsend-Small and Czimczik (2010) estimate that 2700 gallons of gasoline were used by the city of Irvine per month to maintain two million square meters of park area. The impacts associated with fuel use were greater than any other impact considered by about a factor of three or more.

Recycled Content

Products made from recycled content are generally preferable to those made from virgin material in two respects: 1) they do not draw on resources that may be limited; and 2) they address issues of waste. The crumb rubber used as infill in artificial turf fields is made from used tires. Recycled tires that were used in this capacity prevented an estimated 300 million pounds of ground rubber from scrap tires from ending up in landfills in 2007 (Rubber Manufacturers Association, 2009). It typically takes between 20,000 and 40,000 scrap tires to produce enough infill to cover a football field (City of Portland, 2008). The EPA's decree has afforded the opportunity for 4.5% of U.S. scrap tire to be applied as crumb rubber in sports surfacing in 2007 (Rubber Manufacturers Association, 2009).

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Water

With over two-fifths of the world's population currently facing serious fresh water shortages, water scarcity is becoming an increasingly important issue. This figure is expected to get worse, as populations maintain growth, and glacier derived supplies continue to dwindle as a result of climate change. Water shortage has become the single greatest threat to food security, human health, and natural ecosystems (Seckler, 1999). In addition, irrigation not only requires the resource of water, but also needs energy to deliver it to the end user.

From a water standpoint, synthetic surfaces are advantageous over natural grass. Irrigation is a key component in maintaining natural turf. Artificial fields, on the other hand, do not usually require irrigation. Depending on their location and use, synthetic turfs may need to be watered down for cooling in hot temperatures, but the amount of water used for cooling is far less than that used to irrigate grass fields.

In addition to irrigation demands for water, a field's ability to take in storm water is another environmental consideration. There are several environmental problems associated with storm water runoff. In general, natural habitats are better able than impermeable surfaces to absorb storm water. However, synthetic turfs include drainage systems that compensate for their inability to take in water, while grass is poor at absorbing large quantities of water. Duble (1993) notes that runoff can vary greatly due to the seasonal distribution of rainfall. For a mean annual precipitation of 30 inches, runoff can be measured for the following amount at different locations: 3 inches in Nebraska, 6 inches in Tennessee, 12 inches in New York, and 22 inches in the Rockies. The resulting runoff that is created can lead to polluted ecosystems, as the flowing water picks up sediment, petroleum products, pesticides, fertilizers, bacteria, and metals. For example, in 2004, the water quality at San Francisco city beaches fell below quality standards 12 times in a single month, and storm water overflow contributed to over 40 closures during that year (Heal the Bay, 2004). This pollution, as well as other water capacity issues, such as flooding and the need for infrastructure, places stress on financial resources which may be lessened by a natural surface.

While natural turf may result in greater runoff than synthetic surfaces, they result in less aggregate waste water because they are able to absorb and use some of the precipitation. When viewed at a national level, the accumulated affects of water distribution and removal are not inconsequential. In aggregate, 3% of national energy, or a 56 billion kilowatt hours annually, goes to water deliverance and removal (EPRI 2002). This results in the release of approximately 45 million tons of greenhouse gas, when assuming the average mix of energy sources in the country (USEPA 2008). So, between the two field types there is a tradeoff of impacts: natural turfs may contribute to the problematic aspects associated with storm water runoff, while synthetic turfs play a role in issues regarding wastewater management.

Heat Island

One concern with synthetic turf is its role in the heat island effect - the increase of urban temperatures due to the replacement of vegetation with impervious surfaces that radiate

heat. (New York City Department of Health and Mental Hygiene, 2008; Turfgrass Resource Center, 2008; Rosenzweig et al. 2006; New Yorkers for Parks, 2006). This effect occurs when heat from direct sunlight is absorbed by surfaces and then dissipated, raising ambient air temperatures. Urban heat island has an adverse impact on the environment because it increases the demand for cooling energy, intensifies air pollution—such as ground level ozone, and increases heat-related health problems (New York City Department of Health and Mental Hygiene, 2008; Rosenzweig et al. 2006; San Francisco Recreation and Park Department, 2008). Since synthetic turf has been shown to be hotter than the surrounding air and other surfaces (see Section 2.2: All-weather availability), it is a contributor to the heat island effect. However, the New York City Department of Health and Mental Hygiene (2008) notes that in New York, where summer temperatures can be about seven degrees higher than surrounding areas, synthetic turfs only make up a small portion of absorbent surfaces in the city, and therefore is not the primary culprit for this phenomenon.

2.8.2 Life Cycle Analysis

Various researchers have considered the emissions impact associated with turf systems, with much of this work focusing on calculating the capacity of natural grass to sequester carbon (Milesi, et al., 2005; Bandaranayake, et. al., 2003; Qian and Follett, 2002; Pouyat etal., 2009). Additional studies have investigated the N2O emissions of turfgrass (Guilbault and Matthias, 1998; Kaye et al., 2004; Bijoor et al., 2008; Hall et al., 2008). Townsend-Small and Czimczik (2010) note a lack of research investigating impacts of organic carbon storage and greenhouse gas (ghg) emissions. Additionally, studies exploring the emissions impacts of synthetic systems are lacking. One study by the Athena Institute (2007), a Canada-based nonprofit, compares the global warming impacts of natural and synthetic turf systems over the lifespan of the systems. This exploration of greenhouse gas inventories over the entirety of their life cycle will be utilized below to evaluate the emissions impacts of natural and synthetic turf systems. Given the scope of this study, our purpose here is not to conduct a comparative life-cycle analysis on turf systems, but rather, to provide some rough estimates of the comparative global warming impacts of natural and synthetic fields to see if we can clearly identify which field system has a lower impact.

The Athena Institute (2007) study considers the entire scope of the product's life-cycle by means of SimaPro 7 LCA Software (2006). Assessments take into account various aspects of a playing field's life-cycle, including: the manufacturing of system components; transportation; surface preparation; maintenance; and end of life considerations. Impacts were calculated using various databases in conjunction with the SimaPro 7 LCA Software, based on the location where impacts occurred. For instance, the primary backing material, "Thioback Pro," is made from substances manufactured in the Netherlands, and is evaluated using the prominent European Life Cycle Inventory database, EcoInvent Library v.1.2, to estimate associated emissions. The Franklin 98/01-update Life Cycle Inventory database from the SimaPro 7 LCA Software was also used in calculations.

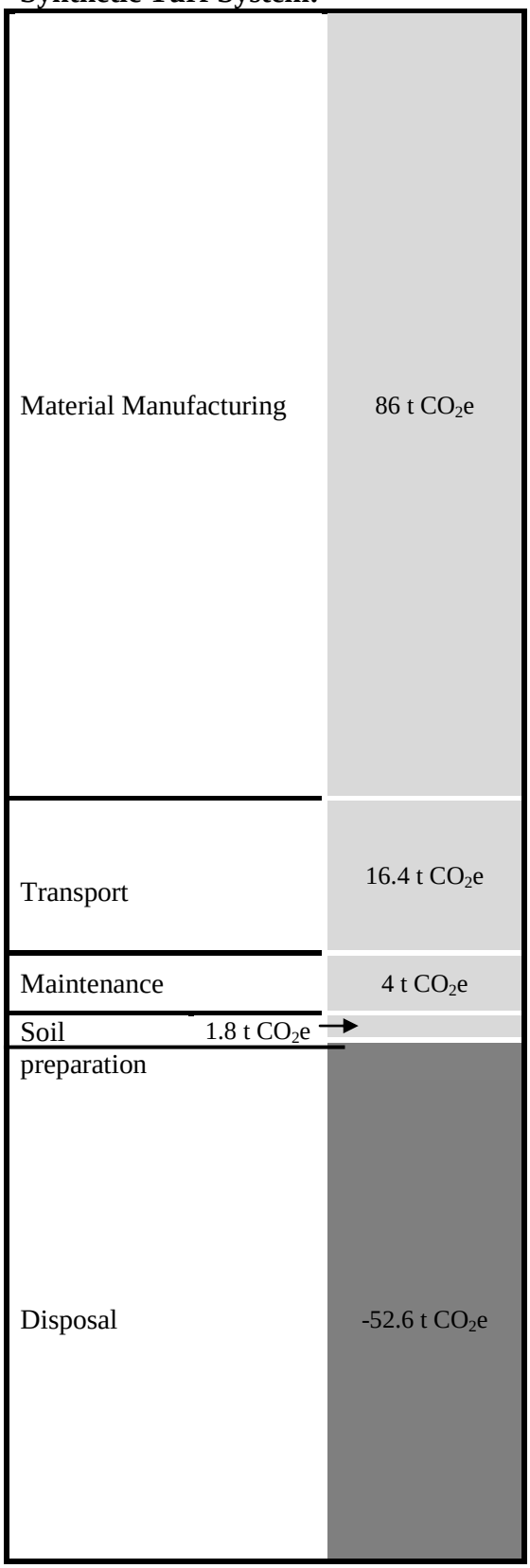
The data for this research was gathered from a case study on the installation of a synthetic field in 2006 for Upper Canada College, a school serving elementary and secondary

students. The size of the field being considered was nine thousand square meters, or approximately 96,875 square feet. Five pieces were identified in construction of synthetic turf fields: the turf itself, primary backing material, a secondary elastomeric coating, rubber granule infill, and PVC piping for drainage. Meanwhile, the only components determined for natural fields are seeds and sod. Transportation includes all emissions from supplier to installation. Maintenance levels for artificial turf systems are adopted from the FIFA (2001) Guide. These include the brushing and removal of debris and contaminants using equipment such as: drag brushes, mats, and nets, hand tools, high-pressure cleanser, and sweeping machines. In addition, watering is recommended as needed, as is the removal of any snow, weeds, algae, and moss. In contrast, the maintenance considered for grass was irrigation and cutting, although the specifics about the methodology, amount, and frequency were not explicitly stated. Lastly, it is assumed that at the end of the artificial turf's life, the system is recycled.

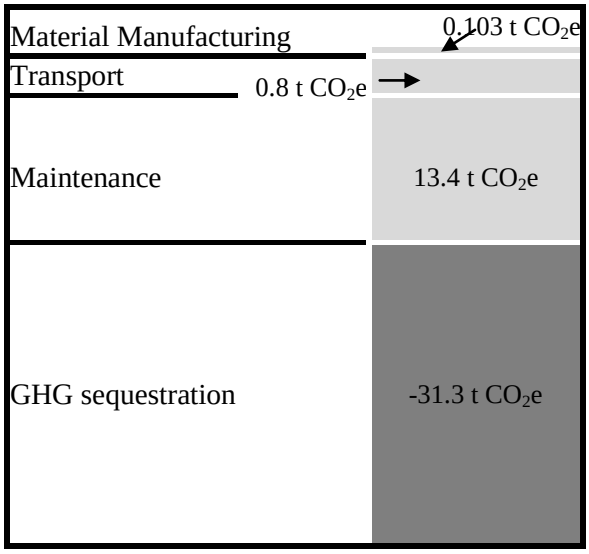
Figure 2.2 below shows a summary of the comparative impacts found by the Athena Institute. Following that is a discussion of their findings.

Figure 2.2: Athena Institute's Green House Gas Emissions Assessment for Field Turf Systems

Synthetic Turf System:



Natural Grass



Material Manufacturing & Transport

The Athena Institute considers the embodied energy for the components of natural and synthetic turf installations. In addition, transportation impacts for these components are calculated via the Upper Canada College case study.

For synthetic fields, the Athena Institute's calculations provide a good estimate for the impacts associated with the production of turf components. The parts that they considered were consistent with other descriptions of artificial turf systems. Also, evaluations for these impacts were conducted using widely accepted LCA software. At present, there is no other literature that considers the global warming impacts of synthetic turf systems. As such, it will be assumed that the Athena Institute's analysis of the impacts for manufacturing synthetic turf components has been adequately executed, and is equivalent to 86 t CO_2e.

For natural grass fields, meanwhile, the only components considered are the production of seeds and sod. The impacts of seed production have generally not been accounted for in research analyzing crop cultivation. This is especially true with urban fields. When evaluating the energy requirements of crop inputs, Moerschner and Gerowitt (2000) find that the effects of seed production are only a mere fraction of the total environmental impacts of fertilizer production. Flessa et al. (2002) cites the negligible contribution of seed production compared to the other agricultural product inputs as the reason for their exclusion in analysis. While attempts have not been made to account for the global warming emissions associated with seed production in grass fields, proposals for the inclusion of seed production have been made in the field of livestock production (Schils et al., 2007; Olesen et al., 2006), as well as in agricultural analysis in Europe (Weiske A., 2006; Kaltschmitt and Reinhardt, 1997).

It is unclear whether the entire scope of sod production is considered in the Athena Institute's analysis (i.e. whether the maintenance that goes into the production of sod is included). Much like seed production, there has been very little discussion of the emissions impacts associated with sod production. However, unlike seed production, the embodied global warming potential (gwp) of sod can be extrapolated from the maintenance requirements for grass fields. The next section will be dedicated to investigating whether Athena Institute's figure provides a good approximation based on some simplifying assumptions. First, to address their assessment, we must first explore the work of Townsend-Small and Czimczik (2010) for the data on the various maintenance impacts associated with natural grass turf.

In their study, Townsend-Small and Czimczik (2010) calculate the gwp of urban natural grass turfs, considering their organic carbon storage, direct N2O emissions, and the emissions associated with maintenance. The outcomes of these evaluations vary based on a number of factors, including: fertilization practices, soil moisture, temperature, and the existing soil organic carbon content. Their analysis of existing fields shows that the amount of organic carbon that is stored in natural grass fields is not enough to offset the direct and indirect emissions associated with the field. In fact, they found that in fields that absorb potential greenhouse gases, associated emissions are approximately three to four times

greater. This is especially true in athletic fields, where it is assumed that turfs are installed with sod, instead of seeds--which is often used for ornamental fields. Based on this assumption, athletic fields offer no net sequestration of CO2. More specifically, the addition of transplanted sod results in the addition of organic carbon to the system. While the original soil where the sod was planted is capable of storing organic carbon, the soil on a field with transplanted sod can take up to three decades before it begins to store organic carbon. In addition, maintenance practices such as tilling, aeration, and the re-sodding of dead grass disrupt the storage of organic carbon. The estimates for this study are listed in the table below:

Table 2.8: Townsend-Small and Czimczik' (2010) gwp of Urban Natural Grass Turfs

Impact Considered	Description	GWP (g CO2/m2/yr)
Organic carbon storage	Estimates of the sequestration of organic carbon based on an analysis of physical samples.	513
N2O emissions	A measurement used to estimate some of the impacts of greenhouse gas emissions from turf soil.	45-145
Fuel	This figure includes the emissions associated with the actual fuel requirements to maintain the turf being sampled, totaling about 2x10 6 m2 of park area. The amount of fuel was estimated to be approximately 2700 gallons of gasoline per month. This fuel covers the transport, mowing, and leaf blowing for weekly trimmings and mulching. The global warming potential from this fuel use was then calculated using the EPA's (2005) estimates of 2421 g C for a gallon of gasoline, and Lal's (2004) assessment of combustion efficiency of 85%, which is similar to farm equipment.	1469
Water conveyance	The fields for this study were watered regularly, using recycled wastewater. Impacts associated with irrigation consider the energy required to pump water. Calculations are made using Schlesinger (1999) estimate of 53 g C/m2/yr for associated energy.	193
Fertilizer production	Fields are assumed to be fertilized from two to 15 times per year. Figures provided by Schlesinger (1999), of 1.436 moles of C per mole of N produced, were used in the calculation of embodied emissions associated with the production of fertilizers. The range of emissions impacts varies based on the number of fertilizations.	45-339
Total		**1752-2146**

We will use the data provided by Townsend-Small and Czimczik's (2010), together with Athena Institute's assessments, to make an approximation of what seed and sod production impacts should be. We begin by stating the assumptions used in our analysis. First, we assume that sod is grown for about a year before it is transplanted to a new field. Powell (1999) estimates that a sod crop can be harvested six months to two years after establishment. Next, we assume that, at the very least, sod requires irrigation to grow. If we assume that Athena Institute's measurements for the watering and cutting (i.e. the "maintenance") of a grass field are correct, then the emissions for growing sod should be at

least one year's worth of the watering impacts (sod impacts should be higher than this figure, as there are additional maintenance requirements that have associated emissions). Townsend-Small and Czimczik's (2010) ratio of impacts from fuel and water conveyance are 1469:193 g CO2e/m^2/yr; or more simply put, the fuel related impacts are 7.6 times greater than those from watering. Then, if we apply this ratio to Athena Institute's maintenance associated emission of 13.4 t CO_2e, watering impacts should be 1.56 t CO_2e for 10 years. If, as stated, we assume that the average sod production period is one year, the rough estimate just proposed suggests that the calculation of 0.103 t CO_2e for seed and sod production might be a slight underestimate, when compared to one year of watering. This figure appears to be an even greater underestimate when considering that Athena Institute's estimate includes the impacts from seed production, and that sod is generally fertilized multiple times prior to being transplanted (Powell, 1999a). The apparent under-estimation of these impacts suggests that a more accurate estimate of emissions associated with seed and sod production should be investigated. However, in the scale of the natural turf's life cycle, the production stage emissions will always be dwarfed by the global warming potential of grass maintenance. Thus, research into more precise measurements of seed and sod production emissions will not be addressed within the scope of this paper, and will be left to future research.

Soil Preparation

Depending on the existing condition of a field, significant efforts might be required to excavate topsoil in preparation of turf installation. For the purpose of this report, it is assumed that emissions associated with excavation are significant, and that they should be incorporated into impact inventories. The Athena Institute's analysis includes impacts related to topsoil excavation. However, they do not explicitly outline what is considered in the accounting of these emissions. We speculate that these impacts are associated with the operation of machinery to dig up and haul away topsoil. This theory is supported by the fact that hauling-related emissions do not appear to be included with transport emissions, which are instead focused on the delivery of components to the location of installation. Therefore, having identified possible impacts related to the excavation of topsoil, which are not covered in other aspects of Athena Institute's evaluations, and without alternative assessments available from other research, we will assume that their calculations are an acceptable estimate for excavation related impacts. However, it should be noted that it might be possible to obtain a more accurate measurement from further investigation.

Maintenance

The maintenance requirements considered by the Athena Institute vary dramatically for the two turf types. The maintenance tasks for artificial turf were adopted from the FIFA (2001) guide. These include the brushing and removal of debris and contaminants using equipment such as: drag brushes, mats, nets, hand tools, high-pressure cleanser, and sweeping machines. In addition, watering is recommended as needed, as is the removal of any snow, weeds, algae, and moss. In aggregate, the emissions associated with these activities are 4 t CO_2e over ten years. In contrast, the maintenance considered for grass is irrigation and cutting. The emissions associated with these activities are 13.4 t CO_2e.

The Athena Institute does not state the underlying assumptions that were made in calculations of maintenance related emissions. It is therefore assumed that all of the various aspects relating to these activities were considered, and that calculations are as comprehensive as possible. For instance, evaluations can change based on factors such as: the frequency with which activities are carried out, the methodology used to accomplish a maintenance task, the quantity of materials applied, and the scope of the supply chain considered (i.e. transportation and embodied energy associated with any material used).

While far more maintenance activities are considered for synthetic fields, the global warming potential for the maintenance of natural fields is greater. The differences in these impacts are partially due to grass fields' continual need for additional supplies to sustain their health. Emissions related to the continual input of supplies accumulate over time. The findings of Townsend-Small and Czimczik (2010) show that much of the global warming impacts of grass maintenance are associated with fuel use. On the other hand, the maintenance of synthetic fields only generally requires a capital investment in equipment and labor to carry out tasks. It is customary in LCA research to exclude the impacts of labor. This means that any work done by hand on a field has no associated emissions.

To achieve a more comprehensive analysis, additional maintenance requirements should be considered, as per the maintenance related equipment and supplies identified in Section 2.4: Maintenance. Of particular interest are the additional impacts associated with the application of fertilizer to natural fields. However, it should be noted, that even with the additional consideration of these elements, the general finding by the Athena Institute will remain largely unchanged. That is, the maintenance impacts of natural turfs will be larger than those of synthetic turf, only to a greater degree. However, these impacts will still be much less than the material related emissions associated with the manufacturing of the components of synthetic turf. Any considerations of additional maintenance practices will result in greater emissions being associated with natural systems. This increase will result from the input of materials that are needed in greater quantities, and with greater frequency than for synthetic turfs.

Table 2.9 below lists the maintenance needs and materials identified by the Athena Institute, as well as additional recommendations obtained from the maintenance materials identified in Section 2.4.

Table 2.9: Maintenance Needs and Materials

	Synthetic	**Natural**
Activities Considered	Watering	Irrigation
	Brushing	Mowing
	High-Pressure Cleaning	
	Sweeping	
	Dragging	
Material Inputs Needed	Water	Water
		Fuel
Additional Recommended Input Considerations	Paint	Paint
	Top Dressing	Top Dressing
		Fertilizer

Green House Gas Sinks

Natural Grass

For natural grasses, the photosynthesis process involves the intake of carbon dioxide and results in carbon compounds that enter the soil with root growth or when a plant sheds or dies. These compounds can be stored long-term as soil organic carbon, as well as other soil organic matter. This is significant in the evaluation of global warming impacts because it results in a more permanent removal of carbon dioxide from the atmosphere. Also, in aggregate, the ability of turf to sequester carbon is not insignificant: in 2005, turfgrass covered approximately 1.9% of land in the continental U.S., making it the most widespread irrigated crop (Milesi et al., 2005). As such, any evaluation of the emissions of natural turfgrass should involve the most current and relevant measure that has been proposed for these impacts.

For the measurement of organic carbon storage, the Athena Institute uses the mean value of sequestration rates proposed by Qian and Follett's (2002) of between 0.9 and 1.0 tons of carbon per hectare per year. These estimates come from soil testing data on golf courses in Denver and Fort Collins, Colorado (Qian and Follett, 2002). Bandaranayake, et al., (2003) found similar sequestration rates when modeling organic carbon sequestration in various geographically-based scenarios. The average rate of accumulation over a 30 year period was found to be 1.2 and 0.9 t C/ha/yr for Fort Collins and Denver, respectively. As previously noted, the ability of soil to store organic carbon can be influenced by a multitude of factors. Post and Kwon (2002) showed this to be true in the case of soils that were previously disturbed, which were found to have a lower C sequestration rate of 0.33 t C/ha/yr. These studies indicate that the figure for organic carbon sequestration used by the Athena Institute may be a bit high for a newly installed field, but are acceptable for a life time analysis of the field.

However, one aspect that the Athena Institute neglects in their calculations is the direct ghg emissions that occur from natural grass. While research on the total impacts of greenhouse gases, including absorption and direct emissions, are somewhat nascent, several studies have looked into the N2O emissions of urban turfgrass. Considerations of these emissions do not measure the full impacts of the direct emissions from grasses. However, they do serve to account for some of the impacts of urban grass, and to illustrate the complexities involved in modeling their global warming impacts. Much like organic carbon storage, there are numerous factors that create variability in emissions rates. Several researchers have modeled annual fluxes of N_2O emissions based on their relationship to temperature, soil moisture, and soil organic carbon content (Scanlon and Kiely, 2003; Flechard et al., 2007). Spikes in N_2O emissions have been shown to occur in urban turfs after irrigation or fertilization of the field (Guilbault and Matthias, 1998; Kaye et al., 2004; Bijoor et al., 2008; Hall et al., 2008). Estimates of N_2O fluxes from urban turfs range between 0.05 to 0.6 g N per meters squared per year (Guilbault and Matthias, 1998; Kaye et al., 2004; Groffman et al., 2009; Townsend-Small and Czimczik, 2010). For our purposes, we will use the estimates provided by Townsend-Small and Czimczik for annual N2O emissions, which is the mean of 0.1 to 0.3 g N/m2/yr.

Recycling of Synthetic Turf at the End of Life

Calculations for the end of life of a synthetic turf are based on the assumption that all components, except the rubber granule infill, are 100% recyclable. Based on this assumption, an emissions credit is awarded by the Athena Institute for the end of life of the system. Calculations are made using ICF Consulting's (2005) report on the ghg emissions factor for plastic. The materials that are assumed to be recyclable in synthetic turf are: polyethylene from the turf and primary backing material; polyurethane from a secondary coating; and PVC piping.

The flaw in Athena Institute's estimates for the end of life emissions for synthetic fields is that materials may not be recycled just because they are capable of being recycled. In fact, the San Francisco Recreation and Park Department (2008) notes that the cost and a lack of infrastructure are an issue with the end-of-life recycling of artificial turf. They note that at the time of the report's publishing only one company in the industry recycled turf material. When turf is not recycled, a large amount of waste must be disposed of at the end of the field's useful life. According to the City of Larchmont, California, 400 tons of debris is created when an 80,000 sq. ft. field is replaced (San Francisco Recreation and Park Department, 2008). Given these concerns, the actual rate of recycling is highly questionable, suggesting that emissions credit should not be accounted for in synthetic turf systems.

2.8.3 Environmental Impact Conclusions

In general, the environmental impact of natural grass is more complex than those of synthetic turf. This is due in large part to the fact that natural grass requires the continual addition of inputs to sustain a field's health. As with any agricultural practice, draws on water and the addition of agrochemicals can become problematic. These practices draw on scarce resources and have the potential to effect surrounding ecosystems. Additionally, the maintenance of grass is associated with the use of large quantities of fuel, to mow grass to the appropriate length. The Athena Institute sufficiently shows the weight of these impacts in regards to global warming. However it is recommended that a more comprehensive inclusion of material inputs into grass maintenance be calculated in any future life cycle assessments.

The environmental issues related to synthetic turf mainly revolve around the use and disposal of materials. Many see the use of recycled waste products for field infill as one of the primary benefits of artificial systems. However, such systems also require the use of many virgin materials. As such, the greatest greenhouse gas emissions of either two system types are the impacts associated with the production of synthetic turf components. These material impacts increase the total emissions by a multiplicative factor when considering the entire life cycle, due to related increases in processing and transportation needs.

The validity of the greenhouse gas emissions sinks identified by the Athena Institute is in need of further consideration. It appears that the evaluations associated with these credits are either based on some faulty assumptions or do not take all considerations into account.

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3.0 CONCLUSIONS

This report explored the various aspects of crumb rubber and addressed some of the claims made by various researchers. A look into the existing literature and data supported many of the assertions made about crumb rubber. Crumb rubber and synthetic turf have many traits that make it a beneficial choice for athletic surfaces. Some of the findings that were found indicated that synthetic turf has:

- **Excellent Playability** – Most literature comparing the play quality of natural and synthetic fields suggest that the differences between them have miniscule affects on playability in comparison with variance in the set-up of the field itself. Where differences do emerge, artificial turf appears to be equal to or better than natural turf, due to its greater consistency. While such findings are incomplete, because of the lack of studies that evaluate the newer generations of turf technology, there were no studies that contradicted the superiority of synthetic turf.

- **All-weather Availability** – Synthetic turf is praised for its availability in all weather conditions: more use per year, and a quick install. It can be used quickly after installation, usually within a few days, rather than the weeks it takes for a sod to become robust enough for use. Also, it can be used in snow, and in general is not affected by precipitation due to the drainage system involved. However, high heat can create an obstacle for synthetic turf use, as the surface can become uncomfortable to play on. Since there are means to temper such effects, the field can still be made useable. Also, the use of turfs are not typically greatest during the hottest parts of the year, as sports seasons typically fall in the late summer through the spring. These impairments do not compare to the degree to which natural fields are compromised during rain and snow. With all weather considered, artificial turf has greater availability over natural grass when taking weather into account.

- **Increased Playing Hours** – Studies suggest that average hours of playability in a three-season year for synthetic turfs range between 2,000 and 3,000 hours, with most research pointing toward 3,000 hours. Natural fields, on the other hand, provide far less playability, with studies estimating a range between 300 and 816 hours in a three-season year on average. Weather is an important factor in the reduction of use times for natural turf. Beyond the weather related losses in the capacity of grass fields, all natural fields must be given time to "rest" to allow for growth.

- **Reduced Maintenance** – The value of a field can be determined by its availability and by the amount of maintenance a field requires. Activities that can be classified as grooming are the most important components of maintenance for both turf types. In addition, debris control, additional cleaning, and needs-specific maintenance may be required. In general, natural fields require a more nuanced balance of activities such as mowing, fertilization, and aeration to ensure their health.

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- **Cost-effective Investment** – synthetic turf fields are typically warranted for about 3,000 hours of play per year, with no "rest" required. For schools with sufficient land, it would take three or four natural fields to withstand the usage of one synthetic turf field. Because of its consistent availability, a synthetic turf field is also a reliable source of rental revenue for schools and communities. The study found that the total cost of ownership over a ten year period is 10% - 20% less than a natural turf field, while being 70% or even 80% less on a cost-per-use basis.

- **Generally Safe Application** – Extensive research has pointed to the conclusion that these fields result in little, if any, exposure to toxic substances. A review of existing literature points to the relative safety of crumb rubber fill playground and athletic field surfaces. Generally, these surfaces, though containing numerous elements potentially toxic to humans, do not provide the opportunity in ordinary circumstances for exposure at levels that are actually dangerous. Numerous studies have been carried out on this material and have addressed numerous different aspects of the issue. For the most part, the studies have vindicated defenders of crumb rubber, identifying it as a safe, cost-effective, and responsible use for tire rubber.

- **Fewer Injuries** – Numerous studies have been conducted assessing the likelihood of injury on natural grass and synthetic turf. A more recent study by Meyers (2010) shows that the latest generation of synthetic surface, FieldTurf, is safer to play on than natural grass fields. Through the analysis of the various injuries that occurred over the course of 465 collegiate games, Meyers shows that FieldTurf has lower incidence of: total injuries, minor injuries (0-6 days lost), substantial injuries (7-21days lost), and severe injuries (22 or more days lost). FieldTurf also had significantly lower injury rates that natural turf when comparing across play or event type, grade of injury, or various field conditions and temperatures. In addition, there was no significant difference found in head, knee, or shoulder trauma between the two playing surfaces.

- **Environmentally Friendly** – In general, the environmental impacts of natural grass are more complex than those of synthetic turf. This is due in large part to the fact that natural grass requires the continual addition of inputs to sustain a field's health. These practices draw on scarce resources and have the potential to effect surrounding ecosystems. Additionally, the maintenance of grass is associated with the use of large quantities of fuel, to mow grass to the appropriate length. The environmental issues related to synthetic turf mainly revolve around the use and disposal of materials. Many see the use of recycled waste products for field infill as one of the primary benefits of artificial systems. However, such systems also require the use of many virgin materials. As such, the greatest greenhouse gas emissions of either two system types are the impacts associated with the production of synthetic turf components. These material impacts increase the total emissions by a multiplicative factor when considering the entire life cycle, due to related increases in processing and transportation needs.

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Effectiveness of FieldTurf Artificial Turf for Management of Stormwater

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A. INTRODUCTION

The Maryland Stormwater Management Act of 2007 has created a new paradigm for the management of stormwater in Maryland. The primary goal of the Act is to mimic, after development or redevelopment, pre-development runoff characteristics, to the extent that it is possible. Traditional designs for stormwater management are less likely to mimic predevelopment conditions because they focus on managing large volumes of polluted stormwater rather than treating runoff closer to the source.

The comprehensive design strategy for maintaining predevelopment runoff conditions is referred to as Environmental Site Design (ESD). ESD relies on integrating site design, natural hydrology, and smaller controls to capture and treat runoff. The objective of ESD is to replicate the hydrology and water quality of forested systems. Each ESD practice is intended to incrementally reduce the volume of stormwater on its way to the stream, thereby reducing the amount of conventional stormwater infrastructure. ESD measures are further defined as those that can minimize the use of impervious surfaces and slow down runoff and increase infiltration and evapotranspiration.

The most recent version of the Maryland Stormwater Design Manual identifies various ESD practices that may be used in commercial areas and urban watersheds. While artificial turf is not specifically mentioned, it appears that products such as FieldTurf should be considered as a potential ESD practice in numerous situations. Use of products such as FieldTurf to achieve stormwater targets would be desirable to counties in Maryland who are tasked with meeting draconian stormwater management requirements. However, the infiltration characteristics of artificial turf products such as FieldTurf would need to be identified to determine how they compare to natural turf and perhaps other developed ESD practices (e.g., permeable pavements). This report will provide a preliminary assessment of the suitability and potential use of FieldTurf as an ESD practice.

B. MARYLAND'S CURRENT STORMWATER REGULATIONS

As described above, MDE updated the current stormwater regulations in 2009. As stated in these regulations:

> The criteria for sizing ESD practices are based on capturing and retaining enough rainfall so that the runoff leaving a site is reduced to a level equivalent to a wooded site in good condition as determined using United States Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS) methods (e.g., TR-55). The basic principle is that a reduced runoff curve number (RCN) may be applied to post-development conditions when ESD practices are used. The goal is to provide enough treatment sing ESD practices to address CP_v requirements [i.e., the 24-hour extended of a post-developed 1-year, 24-hour storm event] by replicating an RCN for woods in good condition for the 1-year rainfall event. This eliminates the need for structural practices… If the design rainfall captured and treated using ESD is short of the target rainfall, a reduced RCN may be applied to post development conditions when addressing stormwater management requirements. (MDE 2009)

MDE (2009) set four performance standards for ESD:

- the standard for characterizing predevelopment runoff characteristics for new development projects shall be woods in good hydrologic condition;
- ESD shall be implemented to the [maximum extent practicable] to mimic predevelopment conditions;
- as a minimum, ESD shall be used to address both Re_v [the volume of groundwater recharge that must be maintained] and WQ_v [storage needed to capture and treat the runoff from 90% of the average annual rainfall] requirements; and
- channel protection obligations are met when ESD practices are designed according to the Reduced [RCN] Method…

In order to comply with Maryland's stormwater regulations, an ESD practice must treat the runoff from one inch of rainfall (i.e., P_e = 1 inch) and ESD practices must address the 24-hour extended detention of a post-developed 1-year, 24-hour storm event (i.e., CP_v). If the reduced RCN for a drainage area reflects woods in good condition, then the CP_v has been satisfied. Structural practices must be used to treat any targeted rainfall that is not met by ESD.

<u>For those readers who wish to more fully understand MDE's requirements, and some of the key underlying terms/concepts such as WQ_v, Re_v, and P_e, the following sections titled Water Quality Volume, Recharge Volume Requirement and Volumetric Runoff Coefficient are presented below. Other readers may wish to skip directly to the section titled Runoff Curve Numbers on Page 4.</u>

WATER QUALITY VOLUME

Water quality volume, or WQ_v, is the storage needed to capture and treat the runoff from 90% of the average annual rainfall. WQ_v is measured in acre-feet. WQ_v can be calculated using the following formula:

$$WQ_v = \frac{P_e * R_v * A}{12}$$

where:

WQ_v = water quality volume, in acre feet

Pe = rainfall target used to determine ESD goals and size practices, in inches

R_v = volumetric runoff coefficient

A = site area, in square feet or acres

RECHARGE VOLUME REQUIREMENT

The recharge volume requirement, or Re_v, is the volume of groundwater recharge that must be maintained at a development or redevelopment site. According to MDE (2009):

> This helps to preserve existing water table elevations thereby maintaining the hydrology of streams and wetlands during dry weather. The volume of recharge that occurs on a site depends on slope, soil type, vegetative cover, precipitation and evapo-transpiration. Sites with natural ground cover, such as forest and meadow, have higher recharge rates, less runoff, and greater transpiration losses under most conditions.

Re_v is a fraction of WQ_v, depending on the pre-development soil hydrologic group. Therefore, Re_v and WQ_v are inclusive.

There are two formulas that can be used to calculate Re_v in acre-feet, the percent volume method and the percent area method:

$$Re_v = \frac{S * R_v * A}{12}$$

and

$$Re_v = S * A_i$$

where:

A = site area in acres;

A_i = the measured impervious cover;

S = the soil specific recharge factor (found in Chapter 2 of MDE 2009); and

R_v = the volumetric runoff coefficient.

VOLUMETRIC RUNOFF COEFFICIENT

Volumetric runoff coefficient, or R_v, is used to calculate the water quality volume. It can be calculated using the formula:

$$R_v = 0.05 + 0.009 * I$$

where:

I = the percent impervious cover.

RUNOFF CURVE NUMBERS

Runoff curve numbers (RCN)[1] are used to predict total runoff of a storm event for a given rainfall event. Higher RCNs indicate that less infiltration will occur and that greater volumes of runoff will be produced. There are eight major factors that influence RCN values: hydrologic soil group (HSG); cover type; treatment; hydrologic condition; antecedent runoff condition; urban impervious area modifications; connected impervious areas; and unconnected impervious areas (NRC 1986).

NRC (1986) solves the runoff equations and presents a series of curves and tables that can be used to identify the appropriate value(s) for RCN for a given set of conditions. MDE's 2009 stormwater regulations rely on these curves and tables to identify the target RCN for woodlands (see Table 1, below).

[1] United States Department of Agriculture, Department of Natural Resources Conservation Service (NRC) and other state agencies commonly use the acronym "CN" to represent the runoff curve number. To maintain consistency with MDE and the current stormwater regulations, the acronym RCN is being used throughout this document.

It is quite clear that the soil characteristics exert a very strong influence on the degree of infiltration and runoff. Table 1 indicates that hydrologic soil type A, which typically consists of 90% sand or gravel and less than 10% clay, has excellent infiltration characteristics (RCN = 30). This can be contrasted with soil type D, which typically consists of greater than 40% clay and therefore has a much higher runoff curve number (RCN = 77).

Table 1
RCN Values for Woods

Hydrologic Condition	Hydrologic Soil Group			
	A	B	C	D
Woods	30	55	70	77
Sources: NRC 1986				

NRC (1986) also presents hydrologic curve numbers for open spaces (e.g., lawns, parks, golf courses, cemeteries). This is the type of landuse that artificial turf could be expected to replace. The RCN values for open spaces, depending on the hydrologic condition and hydrologic soil type, range from 39 to 89. Table 2, below, presents the RCN values for this "natural turf."

Table 2
RCN Values for Natural Turf

Hydrologic Condition	Hydrologic Soil Group			
	A	B	C	D
Poor condition (grass cover < 50%)	68	79	86	89
Fair condition (grass cover 50% to 75%)	49	69	79	84
Good condition (grass cover > 75%)	39	61	74	80
Notes: RCN values originally presented for open space/pasture – here defined as "natural turf"				
Sources: NRC 1986				

As can be seen from a comparison of the RCN values presented in Tables 1 and 2, natural turf does not provide the same level of natural stormwater runoff control as does wooded property (i.e., RCN values for natural turf are considerably higher than for woods, for a given landuse). This means that more water runs off of a natural turf site than is allowed under current MDE stormwater regulations for the development (or redevelopment) of a site.

C. FIELDTURF

DESCRIPTION OF PRODUCT

FieldTurf, like other synthetic turf products, consists of four main components: the fiber, (or grass like material), the backing to which the fiber is tied, the infill, and the prepared subsurface. FieldTurf offers a number of different product lines, each with different variations of nylon or polyethylene fibers. FieldTurf's backing is 40% porous; it has a coating applied only along the fiber rows, allowing the remainder of the backing to drain. The infill is a combination of cryogenic rubber and silica sand (FieldTurf Tarkett Undated a).

While FieldTurf's unique coating allows for water to quickly pass through the turf system, overall drainage depends heavily on the quality of the underlying base. In most instances, the turf system will drain anywhere from 5 to 10 times faster than the base; therefore, the most

critical component in a field's drainage performance revolves around the design of the base and the quality of its materials and construction (FieldTurf Tarkett Undated b).

TYPICAL INSTALLATION

The Field Turf system is typically installed to be slightly higher in the center, sloping gradually at 0.5% towards the field's edges. The fibers are underlain with 1 to 2 inches of No. 8 and finishing stone. A free draining gravel subbase consisting of No. 57 stone is installed beneath the No. 8 stone layer. The depth of the No. 57 stone treatment is typically 4-5 inches at the center and gradually thickens to 8 to 9 inches towards the edges of the field. Therefore, the total subsurface depth of stone treatment for FieldTurf typically ranges from 6 to 11 inches. Underdrain systems are provided to enhance drainage and may serve to detain runoff.

D. LITERATURE REVIEW

Effective stormwater management involves addressing both water quality and water quantity concerns to prevent a range undesirable outcomes including biological impairment of surface waters, public health concerns, stream erosion, and downstream flooding. AKRF was tasked with compiling and reviewing existing literature to assess the relative efficacy of natural turf and synthetic turf systems in providing stormwater management.

WATER QUALITY

The effects of turf systems on water quality include both the ability of the turf system to remove pollutants associated with rainwater or incoming stormwater and the potential for pollutants to be generated by turf systems through processes such as erosion or leaching.

Several studies have looked at the potential for water quality impacts associated with artificial turf fields. Generally, these studies have focused on the potential for leaching of heavy metals and lead. The conclusions of most studies has been that the primary water quality concern associated with artificial turf fields is the potential for zinc leaching from crumb rubber. Yet the findings of these studies are certainly not conclusive with respect to toxicity. For instance, a study performed by the New York State Department of Environmental Conservation and New York State Department of Health (2009) concluded that leaching from crumb rubber did not pose a significant risk of groundwater contamination, but found that zinc leaching from crumb rubber made from truck tires could pose a threat to aquatic life. The same study concluded that leaching from crumb rubber made from mixed tires posed an insignificant risk for aquatic life.

A study of four artificial turf fields in Connecticut (Connecticut Department of Environmental Protection, 2010) found that zinc leaching from artificial turf fields was a potential risk to surface waters, but in evaluating the potential risks of stormwater runoff the study goes on to state that, *"Since the mean concentration of zinc in the stormwater samples is below surface water protection criteria, the discharge from the artificial turf fields to groundwater is intermittent, and zinc is immobilized in soils by adsorption, absorption and precipitation, the potential for impacts to surface waters being recharged by this groundwater is minimal."* A recent Montgomery County, Maryland report (Montgomery County Staff Work Group, 2011) reported that samples obtained from an on-going San Francisco Pubic Utilities synthetic turf monitoring study showed total zinc levels above the Maryland Toxic Substances Criteria for Ambient Surface Waters (120 µg/l) standard but showed dissolved zinc levels below the acute toxicity level.

In the same study, a review of literature found that many previous studies have shown that artificial turf fields are generally unlikely to generate pollutant at concentrations above water quality limits, although some studies do indicate that toxic compounds can be released from used tires, which are used to produce the rubber infill material associated with many synthetic turf products, during leachate studies (Montgomery County Staff Work Group 2011). Additionally, one study reported that artificial turf systems have been shown to support lower levels of bacteria than natural turf fields (California Department of Resources Recycling and Recovery 2010).

In summary, there is a perception based on limited studies that zinc can be an issue for aquatic life depending on the type of tires and crumb rubber used. Because the results of the previous studies are neither conclusive nor product specific, we plan on investigating the relationship between FieldTurf and zinc concentrations in stormwater runoff during a second phase field testing project.

Natural turf systems could potentially give rise to a number of water quality concerns including leaching of fertilizer, herbicides, or pesticides and through surface erosion, although these effects can be reduced to varying extents through the use of best management practices. There are also potential environmental risks from spills associated with lawnmower use, which is needed for managing turf systems. We did not locate any studies that quantified these potential impacts.

THERMAL IMPACTS

Increases in water temperature can pose a threat to certain types of aquatic life, particularly cold water fish. Several studies have shown that artificial turf surfaces have significantly higher ambient temperatures than natural turf areas (e.g., NYSDEC/NYSDOH 2009), although these effects can be mitigated by washing down the turf surface. As a result of elevated ground temperatures, surface runoff coming in contact with artificial surfaces could be subjected to higher levels of thermal loading than runoff coming in contact with natural turf, but the amount of temperature increase would be strongly influenced by the contact time between the runoff and turf surface. Also, thermal impacts may be mitigated by the increased potential for infiltration associated with artificial turf surfaces. We did not find any study that specifically compared stormwater runoff temperature between artificial and natural turf surfaces.

INFILTRATION

Infiltrating stormwater into the ground is an effective means for mitigating many of the negative impacts associated with stormwater runoff and has emerged as the stormwater management strategy of choice throughout much of the U.S. The potential for precipitation to infiltrate into the ground is generally a function of the permeability of the ground surface and subsoils.

Infiltration rates associated with natural turf systems vary with a host of factors including the type and density of turf grass, root development, maintenance, compaction and soil characteristics. However, we found few studies that systematically looked at how these characteristics influence infiltration rates. One study by Hamilton and Waddington (1999), who measured infiltration rates associated with 15 residential lawns in central Pennsylvania, provides some insight into the potential range of infiltration rates associated with grass/soil complexes. The study showed that most lawns had infiltration rates less than 1.18 in/hr and that soil characteristics or maintenance were not correlated with infiltration rates.

Logically, engineered natural turf systems (e.g., turf over sand or other engineered media, etc.) may produce much higher infiltration rates than conventional natural turf (e.g., in residential lawns, etc). For instance, Davis (1981) reported compacted infiltration rates for sand samples obtained from nine sports fields in California and found that most infiltrates rates exceeded 20 in/hr.

Laboratory testing provided by FieldTurf reported permeability rates of 139.2 in/hr, suggesting that precipitation moves very rapidly through the turf surface and to the subsurface gravel bed. A study by James and McLeod (2010) looking at the effect of maintenance on the performance of sand filled synthetic turf showed that infiltration rates declined significantly (approximately 18 in/hr at installation to between approximately 2-4 in/hr) as the infill became contaminated by fine material. It is unclear to what extent this effect would be present for rubber filled turf systems or for natural turf.

E. POTENTIAL USE OF FIELDTURF UNDER MARYLAND REGULATIONS

POTENTIAL FOR USE AS AN ESD PRACTICE

Very high surface infiltration rates (up to 139.2 in/hr; TSI 2010) suggest that FieldTurf effectively conveys stormwater from the ground surface to subsurface soils similar to other approved ESD porous alternative surfaces, such as permeable pavements. In fact, the measured infiltration rate associated with FieldTurf appears to be one to two orders of magnitude higher that the 8 in/hr required of permeable pavement in the MDE Stormwater Design Manual. This comparison suggests that FieldTurf is highly porous and will not impede conveyance of stormwater even during high intensity precipitation events.

Given its high infiltration rate, FieldTurf applications offer the potential to infiltrate stormwater to a greater extent than from natural turf fields, provided sufficient subsurface storage (i.e., gravel media) is provided beneath the turf. While typical installation of FieldTurf is not currently identical to the installation of permeable pavements, the installation could be readily adapted to match or be similar to the guidelines set forth by MDE (2009) for permeable pavements (e.g., depth and drainage characteristics of subsurface media, required infiltration rates for subsoils etc.). ESD design guidelines for permanent pavements are presented in Attachment A.

The high surface infiltration rate associated with FieldTurf suggests that it would be appropriate to, at a minimum, apply the RCN values provided in the MDE Stormwater Design Manual for permeable pavers to FieldTurf applications, provided that the installation of the subsurface bed beneath the FieldTurf met, or was similar to, MDE requirements for permeable pavements. A comparison between RCN values associated with natural turf and permeable pavements is presented in Table 3. As is shown, the RCN associated with permeable pavements is a direct function of the hydrologic soil group and the depth of the gravel subbase. Assuming RCN values for permeable pavements could be applied to FieldTurf and comparing those RCN values to RCN values for natural turf, replacing natural turf with FieldTurf systems *could* provide the ability to lower the RCN, particularly if the existing natural turf is in fair or poor condition and if a 12”, or possibly a 9” subbase is used beneath the FieldTurf. However, in other situations (e.g., good condition turf converted to FieldTurf using a shallower gravel bed, etc.) the RCN may be significantly increased when converting from natural turf to FieldTurf, at least according to the RCN values provided in the MDE Stormwater Design Manual.

Based on the typical construction details provided to AKRF, the typical FieldTurf installation consists of a roughly 6 to 11 inch stone layer beneath the FieldTurf system. If we assume that RCNs for FieldTurf would be similar to those presented the MDE Stormwater Design Manual for permeable pavements, in most cases the depth of the gravel layer would need to be increased to provide a substantial reduction in RCN. According to Table 3, providing a 12 in. subbase beneath the FieldTurf system would provide RCN values roughly equaling those provided for a "woods in good condition" target, thus eliminating the need to provide additional treatment for runoff generated by the FieldTurf installation.

Table 3

Comparison Between RCN Values for Natural Turf and Permeable Pavements for Various Hydrologic Condition, Depth of Subbase, and Hydrologic Soil Group (HSG) as Reported in the MDE Stormwater Design Manual

Natural turf					Permeable Pavements					Difference in RCN			
Hydrologic Condition	HSG				Depth of Subbase	HSG				HSG			
	A	B	C	D		A	B	C	D	A	B	C	D
Poor condition (grass cover < 50%)	68	79	86	89	6"	76	84	93	N/A	-8	-5	-7	N/A
	68	79	86	89	9"	62	65	77	N/A	6	14	9	N/A
	68	79	86	89	12"	40	55	70	N/A	28	24	16	N/A
Fair condition (grass cover 50% to 75%)	49	69	79	84	6"	76	84	93	N/A	-27	-15	-14	N/A
	49	69	79	84	9"	62	65	77	N/A	-13	4	2	N/A
	49	69	79	84	12"	40	55	70	N/A	9	14	9	N/A
Good condition (grass cover > 75%)	39	61	74	80	6"	76	84	93	N/A	-37	-23	-19	N/A
	39	61	74	80	9"	62	65	77	N/A	-23	-4	-3	N/A
	39	61	74	80	12"	40	55	70	N/A	-1	6	4	N/A

HYDROLOGIC MODELING OF RCN VALUE FOR FIELDTURF

To further characterize the runoff characteristics associated with FieldTurf applications, AKRF performed a hydrologic modeling study of an existing FieldTurf installation, which had been previously studied by ELA Group, Inc. (2007) (Project No: 103-070, January 9, 2007). The project site is a 6.33 acre watershed located at Coatesville High School in Coatesville, Pennsylvania. This watershed contains a 2.09 acre synthetic turf field that is the subject of this analysis. The approach of this study is to model the hydrologic response of the project site to actual precipitation events and to compare and attempt to match these results to measured runoff data previously collected by ELA Group, Inc. by varying synthetic turf RCN inputs.

AKRF's modeling study utilizes the U.S. Army Corps of Engineers Hydrologic Modeling System (HEC-HMS) and is based on data provided in the report titled Field Test Data Study for the Stormwater Runoff From Synthetic Turf Fields at Coatesville High School, prepared by ELA Group, Inc. (2007). ELA's study included measured runoff from the project site for several precipitation events before and after the conversion of an existing natural turf field to a FieldTurf field. Data utilized from this report for AKRF's modeling study include post development

drainage area cover descriptions and rational method runoff coefficients, time of concentration, field recorded post development peak flow rates and runoff volumes for seven storm events from 9/2006 to 11/2006, and 24 hour rainfall volumes from the Coatesville 2W rain gage (NOAA Station ID: PA361591), which is located 3.68 miles from the project site. These data were supplemented with 15 minute rain gage data from the Glenmoore rain gage (NOAA Station ID: PA363321), located 7.18 miles from the project site. It should be noted that the Post Development Watershed Map that accompanies ELA Group's report was not provided for the analysis.

The project site contains four defined post development land cover classifications, which include impervious modular classrooms, an impervious track, a pervious grass area, and the pervious synthetic turf field. To develop a hydrologic model using NRCS methodology, RCNs were assumed for each land cover based upon soil data and the provided cover descriptions and rational runoff coefficients. The project site lies predominately over Conestoga silt loam (CtB) soil, which is in the 'B' hydrologic soil group. All impervious areas were assumed to have a RCN of 98, and the pervious grass area was assumed to be in good condition based on aerial imagery. The watershed land cover and assumed RCNs used in the hydrologic model are summarized in Table 4. Synthetic turf RCN was isolated and varied as it is the main focus of this hydrologic study.

Table 4
Watershed Land Cover Summary

Land Cover	Area (acres)	RCN
Modular Classrooms	0.83	98
Grass	0.74	61
Impervious Track	2.67	98
Synthetic Turf	2.09	---

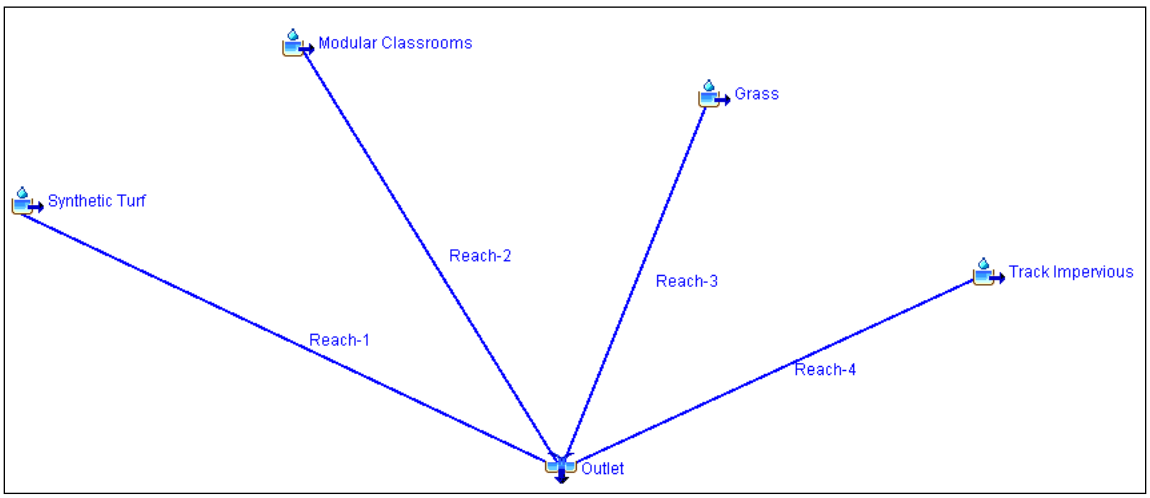
Glenmoore rain gage (NOAA Station ID: PA363321) 15 minute rainfall data were used as the precipitation input for hydrologic modeling. Although the Coatesville 2W rain gage is located closer to the project site, only daily rainfall totals are provided for this rain gage. It is understood that actual rainfall patterns and intensities would more accurately model field recorded peak flow rates than synthetic rainfall distributions based only on daily rainfall totals. Despite the close proximity of both rain gages, differences in total rainfall volumes were observed for the seven rainfall events examined. The rainfall records for these rain gages are summarized in Table 5. Based on the available data, Event #4 (10/17/2006 to 10/18/2006) and Event #6 (10/27/2006 to 10/29/2006) were selected as the events to focus modeling efforts. Event #4 was selected due to the size of the event and the close correlation of total precipitation volumes between both rain gages. Event #6 was chosen because it was the largest event in the provided data set.

Table 5
Rainfall Gage Records

Event Number	Date	Total Recorded Precip. (inches)	
		Coatesville	Glenmoore
1	9/28 to 9/29/2006	0.86	0.6
2	10/1/2006	0.1	0.1
3	10/6 to 10/7/2006	0.56	0.4
4	**10/17 to 10/18/2006**	**0.79**	**0.8**
5	10/19 to 10/21/2006	1.01	0.6
6	**10/27 to 10/29/2006**	**1.74**	**1.9**
7	11/2/2006	0.55	0.4

A schematic of the hydrologic model is shown in Figure 1. All watershed land covers were modeled as individual subareas and assumed to flow directly to the watershed outlet. This assumption was necessary due to the lack of provided information about the physical layout of the watershed and information about the location of the flow recording instrumentation. A time of concentration of 5 minutes was applied to all subareas, as specified in ELA Group's report. A lag time of 1 minute was assumed for each reach.

Figure 1. Hydrologic model schematic



The RCN input for the synthetic turf subarea was varied from a range of 50 to 90. Model results and field recorded data are summarized for total runoff volume in Table 6 and for peak flow in Table 7.

Table 6
Hydrologic Model Runoff Volume Results Summary

Event Number	4	6
Glenmoore Gage Recorded Precipitation Volume (in)	0.8	1.9
Field Recorded Runoff Volume (in)	**0.12**	**0.57**
Model Total Runoff Volume (in)		
Turf RCN=50	0.33	0.93
Turf RCN=60	0.33	0.94
Turf RCN=65	0.33	0.96
Turf RCN=70	0.33	1.00
Turf RCN=75	0.33	1.04
Turf RCN=80	0.34	1.09
Turf RCN=85	0.36	1.17
Turf RCN=90	0.39	1.26
Model Runoff Volume from Impervious Areas (in)	0.33	0.93

Table 7
Hydrologic Model Peak Flow Results Summary

Event Number	4	6
Glenmoore Gage Recorded Precipitation Volume (in)	0.8	1.9
Recorded Peak Flow (cfs)	**0.20**	**1.21**
Model Peak Flow (cfs)		
Turf RCN=50	1.3	1.4
Turf RCN=60	1.3	1.5
Turf RCN=65	1.3	1.6
Turf RCN=70	1.3	1.7
Turf RCN=75	1.3	1.8
Turf RCN=80	1.5	1.9
Turf RCN=85	1.6	2.0
Turf RCN=90	1.8	2.1

The hydrologic model results consistently predict higher observed runoff volumes for both Event #4 and for Event #6. In fact, the predicted runoff volume from the impervious areas alone (modular classrooms and impervious track) is greater than the actual observed runoff for both events. Peak flow rates are also over predicted for both events.

These results led to the conclusion that the difference between the modeled runoff volume and observed runoff volume has been stored or infiltrated by the pervious watershed areas, which include the grass area and the synthetic turf. This infiltrated volume could potentially be as great as 0.21 inches for Event #4 and 0.36 inches for Event #6. The difference in peak flow rate may also be a result of this removed runoff volume. While there is strong evidence to support these conclusions, further watershed information is necessary to begin to isolate the stormwater management benefits of the synthetic turf from those of the natural grass area. The Post Development Watershed Map that accompanies ELA Group's report, site survey data if available, and a detailed site inspection may offer further insight. If watershed mapping confirms that newly constructed impervious areas drain to the FieldTurf area, **the study may**

suggest that the effective RCN for the FieldTurf installation is actually much lower than reported RCN values for porous pavement provided in the MDE manual.

It is the recommendation of AKRF that an additional field study is necessary to conclusively assess and relate the stormwater management performance and benefits of FieldTurf's synthetic turf system to the NRCS RCN methodology. Ideal study conditions would consist of an isolated synthetic turf system specifically designed for observation, and outfitted with instrumentation to record and log onsite precipitation, inflow, and outflow.

F. ADVANTAGES OF USING FIELDTURF

Field Turf offers many advantages to natural turf and is more consistent with sustainability initiatives being implemented both in Maryland and on the national level. Maintenance costs are substantially lower for artificial turf products and far fewer days are lost in terms of usage due to field conditions. Furthermore, FieldTurf does not require labor associated with frequent mowing or striping of natural turf athletic fields. The use of gas powered mowers on natural systems also results in air emissions of metals and hydrocarbon breakdown products.

In addition, there are a number of stormwater management advantages to the use of artificial turf, specifically FieldTurf. These include:

WATER QUANTITY IMPROVEMENTS

DRAINAGE

Artificial turf has superior water drainage characteristics, when compared to natural turf. It was designed to drain water to limit the periods of time that an athletic field is unavailable for play due to a storm event. This capability to drain rainfall is also beneficial when considering ways to manage stormwater, increasing infiltration and limiting the amount of runoff that leaves the field/site.

REDUCTION IN PEAK STORMWATER FLOW

Stormwater that falls on artificial turf must travel through the different components of the artificial turf product before entering a natural waterway, including the infill turf, infill, backing, and subsurface. This results in a reduction in the peak stormwater flow to the waterway, which can have positive effects, such as a reduction in erosion.

WATER QUALITY IMPROVEMENTS

DECREASE IN FERTILIZER AND PESTICIDE USE

Artificial turf (e.g., FieldTurf) does not require the traditional lawn supplements that are necessary to maintain healthy natural turf. Among other inputs, this includes fertilizers and pesticides. Fertilizers and pesticides can and do wash off of natural turf in a rain event, degrading downstream water quality. The use of artificial turf can improve the quality of any stormwater that does leave the site and minimize the requirements for stormwater quality controls.

FILTRATION

Artificial turf can act as a filter, capturing solid material suspended in stormwater that flows over and/or through the surface. This filtering action can reduce the phosphorus and sediment load carried by the stormwater that ultimately reaches natural waterways, thereby improving water quality.

G. EXPERIMENTAL DESIGN AND STUDY PLAN FOR A FIELD TESTING PROGRAM – RELATIVE EFFICIENCY OF FIELDTURF VS. NATURAL TURF FOR MANAGING STORMWATER

Further experimental testing could help to refine appropriate RCNs for FieldTurf applications. As is reflected in the RCN values provided in the MDE Stormwater Design Manual for porous pavement, RCNs for Field Turf applications are likely to be a function of both the depth of the underlying subsurface gravel bed and the Hydrologic Soil Group associated with the subgrade material.

Given these parameters, an effective experimental design to develop RCNs for FieldTurf applications would systematically vary both Hydrologic Soil Group (i.e., A, B ,C) and Gravel depth (i.e., 6 in., 9 in., and 12 in.) Thus, nine (9) experimental plots would be required to fully capture the range of possible hydrologic soil groups and gravel depth combinations. Ideally, each plot would be replicated, yielding a total of 18 plots.

Individual plots should be identical in size and slope and should be located in a similar geographic area to permit the use of directly comparable precipitation data. Plots should be located on mildly sloping ground (no more than 5% slope) and should be at least 50 ft. x 50 ft. in size. Plots should be located on open ground with no overhanging cover.

To measure surface runoff from the site, the drainage area associated with each field plot must be isolated. If possible, plots should be located at or near a natural drainage divide to avoid the necessity of rerouting upstream flow around the plots. However, if needed, small earthen berms can be constructed at the upstream extents of the plots to redirect upstream flows.

Surface runoff from the each plot should be collected into a downslope piping system or earthen channel. Since the plots are small, a relatively modest channel or piping network will suffice. AKRF would develop a flow rating curve for the conveyance channel or pipe using manual velocity measurements. Flow stage within the pipe or channel would then be measured continuously using pressure transduction and converted to discharge measures using the aforementioned rating curve. Alternatively, flow could be conveyed to a weir structure and discharge could be calculated using standard equations for weir flow by measuring the flow stage at the weir.

In addition to flow monitoring, the FieldTurf test plots could be used to evaluate the effects of FieldTurf on water quality, both for surface water and water that is infiltrated through the turf system. Evaluation of surface water quality would involve collection of flow-weighted water samples using an ISCO sampler or similar automated sampling device. Typical constituents of interest would include nitrate, nitrate, ammonia, dissolved phosphorus, total phosphorus, total suspended solids, and toxic metals. Measured concentrations could be either compared with rainwater samples collected near the test plots, or alternatively with surface runoff collected from a nearby control plot (i.e., a similarly sized plot covered with natural turf). Collection of water quality samples to characterize infiltrated rainwater would involve the collection of infiltrated water via an underdrain system located beneath the porous gravel bed.

The final experimental design will depend on further coordination with FieldTurf representatives. We do note that the experiment design described above represents an ideal configuration. However, less intensive studies may yield useful, although perhaps not as widely applicable results. Accordingly, the experimental design can be simplified/reduced as needed to accommodate available resources. For instance, a smaller experimental design could be

developed using only Hydrologic Soil Groups A and C and gravel depths of 6" and 12". We would also need to coordinate with FieldTurf to determine whether any of their existing installations could be useful or modified for incorporation into our experimental design.

Once an experimental design is developed and agreed upon, we may wish to coordinate with MDE prior to conducting additional field studies.

H. COMPARISON WITH OTHER PRODUCT

AKRF compared permeability rates associated with FieldTurf to another leading synthetic turf product (AstroTurf Gameday Grass). It appears that FieldTurf had much higher permeability rates (139.2 in./hr vs. >30 in/hr) than AstroTurf using the same test (ASTM F1551-03). Even if AstroTurf's permeability rate were doubled to 60 in/hr, it would still be less than half of that for FieldTurf. Therefore, if both products used the same subsurface treatment, it is reasonable to assume that FieldTurf would exhibit substantially better infiltration characteristics for stormwater management purposes. Both products have infiltration rates that are significantly higher than the 8.0 in/hr required for permeable pavement by the MDE Stormwater Design Manual.

I. CONCLUSION

A number of approaches were developed that suggest FieldTurf has considerable promise as an ESD practice under the Maryland Stormwater regulations. FieldTurf's infiltration potential appears to be as good or superior to that of permeable pavements, which is an accepted ESD practice. Results of a hydrologic model applied to field data from the Coatesville High School study further support these findings and suggest that RCNs for FieldTurf may be lower than those for permeable pavements. However, additional experimental testing to refine the appropriate runoff curve numbers for FieldTurf applications is needed before a case for ESD can be made to the Maryland Department of the Environment.

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Attachment A

A-2. Permeable Pavements

Permeable pavements are alternatives that may be used to reduce imperviousness. While there are many different materials commercially available, permeable pavements may be divided into three basic types: porous bituminous asphalt, pervious concrete, and permeable interlocking concrete pavements. Permeable pavements typically consist of a porous surface course and open graded stone base/subbase or sand drainage system. Stormwater drains through the surface course, is captured in the drainage system, and infiltrates into the surrounding soils. Permeable pavements significantly reduce the amount of impervious cover, provide water quality and groundwater recharge benefits, and may help mitigate temperature increases.

Applications:

Permeable pavements are effective for reducing imperviousness in pedestrian pavements, parking lots, driveways, plazas, and access roads. They may be used in both new and redevelopment applications in residential, commercial, and industrial projects. Permeable pavements are particularly useful in high-density areas where space is limited.

Performance:

When designed according to the guidance provided below, areas covered by permeable pavements will have runoff characteristics more closely resembling vegetated areas. The capacity of permeable pavements to capture and detain runoff is governed by the storage capacity, compaction of the soil subgrade, and in-situ soil properties. Consequently, RCN's applied to these systems vary with individual design characteristics. The effective RCN's shown in Table 5.5 are used when addressing the ESD Sizing Criteria.

Constraints:

The following constraints are critical when considering the use of permeable pavements to capture and treat stormwater runoff:

- **Space:** The size and distribution of paved surfaces within a project must be considered early during planning and design. Permeable pavements should not be used in areas where there are risks for foundation damage, basement flooding, interference with subsurface sewage disposal systems, or detrimental impacts to other underground structures.

- **Topography:** Runoff should sheetflow across permeable pavements. Pavement surfaces should be gradual (≤ 5%) to prevent ponding of water on the surface and within the subbase.

- **Soils:** Sandy and silty soils are critical to successful application of permeable pavements. The HSG should be A, B or C.

Subsurface water conditions (e.g., water table) will help determine the stone reservoir thickness used. The probability of practice failure increases if the reservoir intercepts groundwater. Therefore, subbase inverts should be above local groundwater tables.

- **Drainage Area:** Permeable pavements are an at-source practice for reducing the effects of impervious cover and addressing ESD criteria. As the impervious area draining to each practice increases, practice effectiveness weakens. Therefore, runoff from adjacent areas (or "run-on") should be limited.

- **Hotspot Runoff:** Permeable pavements should not be used to treat hotspots that generate higher concentrations of hydrocarbons, trace metals, or toxicants than are found in typical stormwater runoff and may contaminate groundwater.

- **Structure:** Most permeable alternatives have a lower load bearing capacity than conventional pavements. Therefore, applications should be limited to locations that do not receive heavy vehicle traffic and where sub soils are not compacted.

- **Operation:** Permeable pavements are highly susceptible to clogging and subject to owner neglect. Individual owners need to be educated to ensure that proper maintenance and winter operation activities will allow the system to function properly.

Design Guidance:

The following conditions should be considered when designing permeable pavements:

- **Conveyance:** *Runoff shall flow through and exit permeable pavements in a safe and non-erosive manner.* Permeable pavements should be designed off-line whenever possible. Runoff from adjacent areas should be diverted to a stable conveyance system. If bypassing these areas is impractical, then runoff should sheetflow onto permeable pavements.

  Pavement surfaces shall have a permeability of eight inches per hour or greater to convey water into the subbase rapidly. The slope of the permeable pavement shall be no greater than 5%. Any grade adjustments requiring fill should be accomplished using the subbase material. Permeable pavements may be placed in sloped areas by terracing levels along existing contours.

  Pavement systems should include an alternate mode for runoff to enter the subbase reservoir. In curbless designs, this may consist of a two-foot wide stone edge drain. Raised inlets may be required in curbed applications.

  The bottom of the subbase shall be level to enhance distribution and reduce ponding within the reservoir. A network of perforated pipes may be used to uniformly distribute runoff over the bed bottom. Perforated pipes may also be used to connect structures (e.g., cleanouts, inlets) located within the permeable pavement section.

All permeable pavements shall be designed to ensure that water surface elevations for the 10-year 24 hour design storm do not rise into the pavement to prevent freeze/thaw damage to the surface. Designs should include overflow structures like overdrains, inlets, edge drains, or similar devices that will convey excess runoff safely to a stable outfall.

- **Treatment:** All permeable pavement systems shall meet the following conditions:
  - *Applications that exceed 10,000 ft^2 shall be designed as infiltration practices using the design methods outlined in Appendix D.13 for infiltration trenches. A porosity (n) of 30% and an effective area of the trench (A_t) equal to 30% of the pavement surface area shall be used.*
  - *A subbase layer of a clean, open graded, washed aggregate with a porosity (n) of 30% (1.5" to 2" stone is preferred) shall be used below the pavement surface.* The subbase may be 6", 9" or 12" thick.
  - *Filter cloth shall not be used between the subbase and soil subgrade.* If needed, a 12" layer of washed concrete sand or pea gravel (⅛" to ⅜" stone) may be used to act as a bridging layer between the subbase reservoir and subsurface soils.

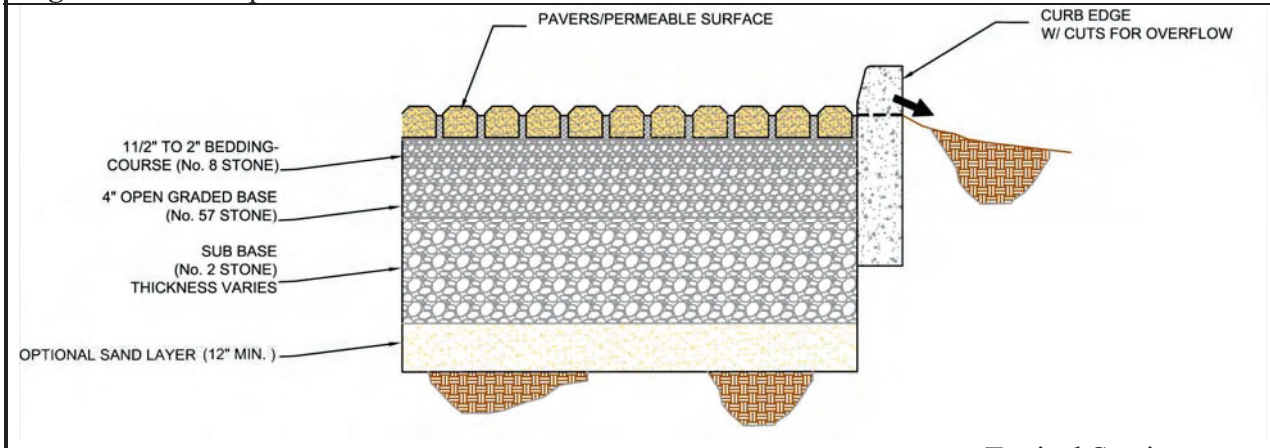
Table 5.5 Effective RCNs for Permeable Pavements

Subbase	Hydrologic Soil Group			
	A	B	C	D
6"	76[1]	84[1]	93[2]	–
9"	62[3]	65[3]	77[3]	–
12"	40	55	70	–

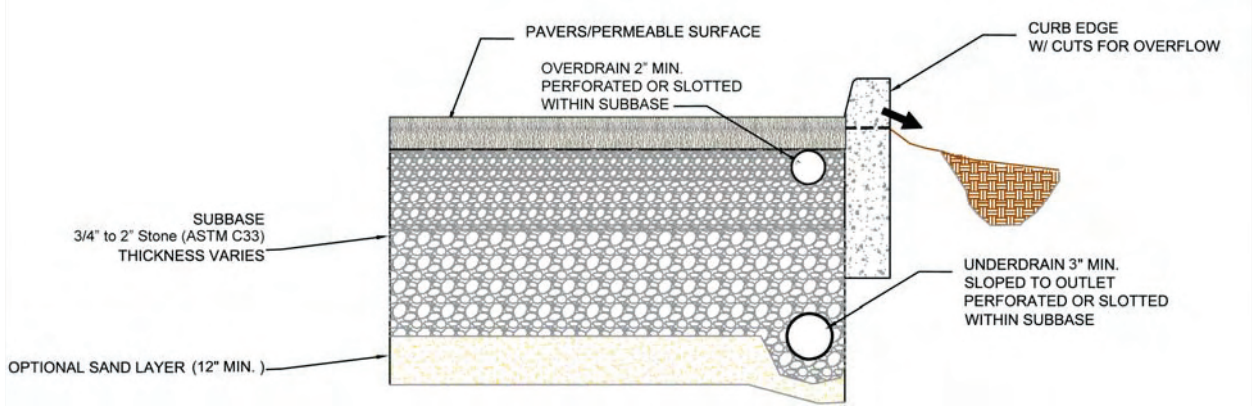
1. Design shall include 1 - 2" min. overdrain (inv. 2" below pavement base) per 750 s.f. of pavement area.
2. Design shall include 1 - 2" min. overdrain (inv. 2" below pavement base) per 600 s.f. of pavement area
3. Design shall include 1 - 3" min. overdrain (inv. 3" below pavement base) and a ½" underdrain at subbase invert.

- **Soils:**
  - *Permeable pavements shall not be installed in HSG D or on areas of compacted fill. Underlying soil types and condition shall be field-verified prior to final design.*
  - *For applications that exceed 10,000 ft^2, underlying soils shall have an infiltration rate (f) of 0.52 in/hr or greater.* This rate may be initially determined from NRCS soil textural classification and subsequently confirmed by geotechnical tests in the field as required in Chapter 3.3.1.
  - *The invert of the subbase reservoir shall be at least four feet above (two feet on the lower Eastern Shore) the seasonal high water table.*

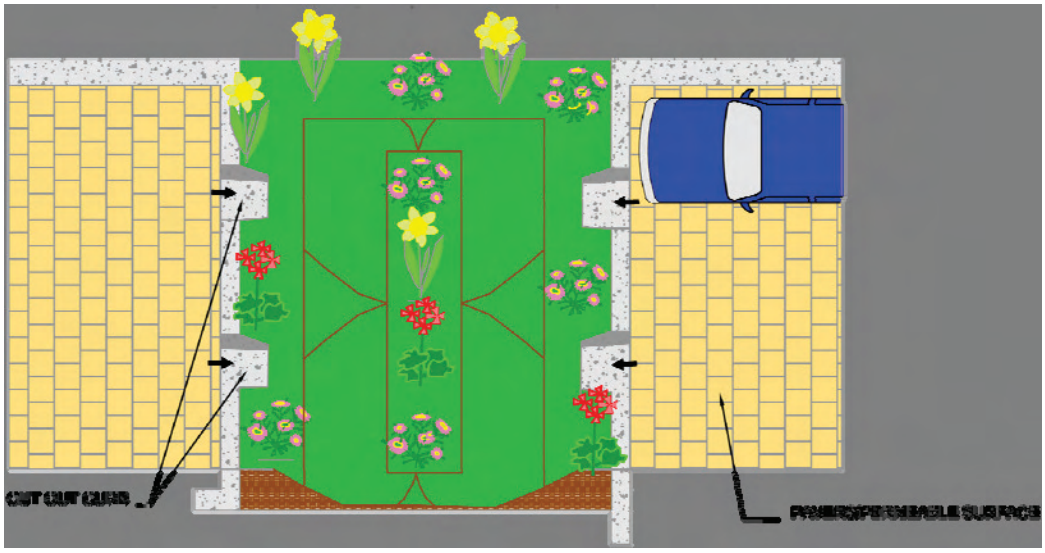
Figure 5.3 Examples of Permeable Pavements



Typical Section



Typical Section w/Overdrain & Underdrain



Permeable Pavement w/Micro-Bioretention - Plan View

- **Setbacks:**
  - *Permeable pavements shall be located down gradient of building structures and be setback at least 10 feet from buildings, 50 feet from confined water supply wells, 100 feet from unconfined water supply wells, and 25 feet from septic systems.*
  - Permeable pavements should also be sized and located to meet minimum local requirements for underground utility clearance.

- **Structure:** *All permeable pavement systems shall be capable of bearing the anticipated vehicle and traffic loads.* Pavement systems conforming to the specifications found in Appendix B.4 should be structurally stable for typical (e.g., light duty) applications.

- **Landscaping:** *Permeable pavement shall be identified on landscaping plans.* Trees and shrubs should not be located adjacent to asphalt and concrete if damage by root penetration and clogging from leaves is a concern.

Construction Criteria:

The following items should be addressed during construction of projects with permeable pavement:

- **Erosion and Sediment Control:** Final grading for installation should not take place until the surrounding site is stabilized. *If this cannot be accomplished, runoff from disturbed areas shall be diverted around proposed pavement locations.*

- **Soil Compaction:** *Sub soils shall not be compacted.* Construction should be performed with lightweight, wide tracked equipment to minimize compaction. Excavated materials should be placed in a contained area.

- **Distribution Systems:** *Overdrain, underdrain, and distribution pipes shall be checked to ensure that both the material and perforations meet specifications (see Appendix B.4). The upstream ends of pipes should be capped prior to installation.* All underdrain or distribution pipes used should be installed flat along the bed bottom.

- **Subbase Installation:** *Subbase aggregate shall be clean and free of fines. The subbase shall be placed in lifts and lightly rolled according to the specifications (see Appendix B.4).*

Turf Talk

CRYOGENIC VERSUS AMBIENT RUBBER

VOLUME 2

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Turf Talk

CRYOGENIC VERSUS AMBIENT RUBBER

vol. 2

There are a several factors which contribute to the safety and performance characteristics of an artificial turf field. None of which are more important than the composition and quality of the infill. The infill is the athlete's source for cutting, planting, shock absorption and energy restitution. While the majority of the competition uses a loose and spongy all ambient rubber system, FieldTurf only incorporates a patented layered infill system that is comprised of silica sand and premium cryogenic rubber.

When it comes to a field's infill, FieldTurf goes to great lengths to guarantee its customers that nothing but the highest quality materials are used in order to assure consistent and reliable results. Cryogenic rubber is the highest and rarest grade of rubber granule. When you grind up a rubber tire approximately only 4% of that tire is suitable for cryogenic rubber processing while the remaining 96% is set aside for ambient processing. Due to the limited supply of cryogenic rubber the product is not easily obtainable. FieldTurf however, has gone to great lengths in order to secure large quantities of this rare, high quality product.

During the grinding phase ambient rubber is simply processed through a high powered rubber cracker mill. The result is a jagged inconsistent rubber granule which has the tendency to degrade rapidly over time. When used as an infill component, ambient rubber has the propensity to float and scatter as the air bubbles located within the rubber facilitate simple infill migration. The process of grinding the rubber is referred to as ambient because all size reduction steps take place at or near ambient temperatures, i.e. no cooling is applied to make the rubber brittle before grinding.

The process of creating a cryogenic rubber granule requires a substantial amount of time and technical manipulation. First, a rubber tire is grinded through a mill. Then the smooth clean particles are separated from the dirty jagged ambient ones. Once separated, the rubber is then frozen to a temperature of below –80 degrees Celsius (-112 degrees Fahrenheit). Cryogenically freezing the rubber allows for a cleaner more glass-like partition of the rubber. While the rubber is still frozen it is placed through a specialized mill which then carefully and cleanly cuts the frozen rubber into small, smooth and rounded particles. The cryogenic freezing process also helps to prevent the formation of any loose or stray rubber strands which reduce the overall quality of the rubber.

When it comes to the topic of drainage, Cryogenic rubber works to promote effective and consistent drainage by eliminating the potential for migration caused by water. The cryogenic rubber's smooth and rounded shape facilitates a consistent flow of water through the infill without raising and displacing any rubber. The loose and jagged rubber strands found in ambient rubber make it highly vulnerable to migration and floatation caused by the air bubbles in water. Even though the specific gravity of ground rubber is about 1.14 (slightly heavier than water) if there are enough air bubbles attached to the rubber, it will float. As the ambient system drains, the rubber floats and is easily dispersed. As a result, empty pockets may form which can be extremely hazardous to the athlete.

Figure 1: Ambient rubber (on the left) compared to Cryogenic rubber (on the right) as it responds to water

Figure 1 more clearly depicts the difference and discrepancy between ambient and cryogenic rubber as it reacts to water. The glass on the left consists of ambient rubber while the glass on the right consists of cryogenic rubber. When mixed with water the ambient rubber

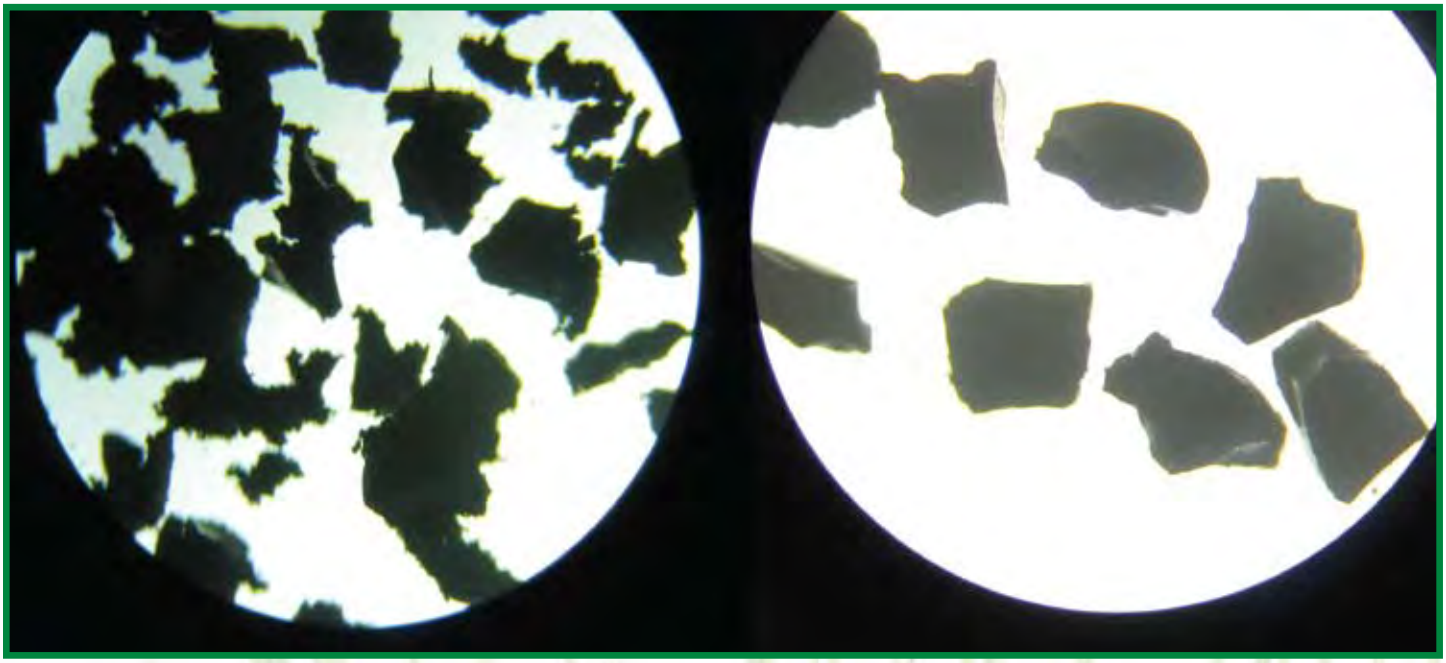

Figure 2: On the left - Ambient rubber. On the right - Cryogenic rubber

proved to be highly susceptible to migration as it floated easily to the surface of the glass. The cryogenic rubber on the other hand, was able to maintain its composure and position even in the presence of water.

Another benefit of cryogenic rubber revolves around its ability to effectively combine with silica sand. Sand is an integral component to the infill mix as it facilitates proper energy restitution. Without sand the infill tends to be overly soft to the point where excessive amounts of energy are needlessly expended. Using the analogy of running on the beach, an all rubber system can be compared to running in the loose and tiring soft sand, where as FieldTurf's sand and cryogenic rubber system can be compared to running along the shore line. The round and consistent shape of the cryogenic rubber assures that the silica sand and cryogenic rubber synthesize in a way that promotes consistency within the infill. By essentially playing off one another, the silica sand and cryogenic rubber come together to form a solid bond. It is that bond which holds the field's fibers firmly in place while offering a safe cushion for the athlete's body, joints and muscles. Ambient rubber's largely inconsistent size does not allow it to smoothly combine with sand. As a result, the sand and rubber which may be situated within the field can easily shift and disperse when played on.

When it comes to cleanliness and safety FieldTurf doesn't take chances, which is why FieldTurf fields are only installed with cryogenic rubber. There is a substantial difference in the cleanliness levels of cryogenic rubber versus ambient rubber. Ambient rubber is mass produced and doesn't require a great deal of manipulation to create. As a result the granules of ambient rubber which have been torn and shredded from a rubber tire contain many particles besides rubber. While cryogenic rubber consists of rounded, smooth pieces of rubber, ambient rubber contains traces of dirt, steel and other metals which were not removed in the grinding process.

The following images are of ambient and cryogenic rubber as seen through a microscope. As you can see in Figure 2, the ambient rubber is dirty with jagged edges that facilitate infill migration while the cryogenic rubber is smooth and rounded.

It is clear that a significant difference exists between ambient and cryogenic rubber. The cryogenic freezing

process manipulates the rubber in order to produce a clean, round, consistent and non abrasive rubber granule which doesn't float or shift when played on. Ambient rubber is dirtier and jagged. It often contains traces of unwanted metal and has the tendency to float when mixed with water or air. As a result, fields that incorporate an ambient rubber infill often tend to be less consistent and are more likely to experience field deterioration and infill migration than fields installed with cryogenic rubber.

Figure 3: Ambient rubber infill migration towards the extremity of this all rubber field.

Figure 4: The FieldTurf at Dick Bivins Stadium is 10 years old! It consists of a Cryogenic rubber and silica sand layered infill. Even after 10 years there exists no signs of infill migration!

Characteristics of Rubber Infill

Parameter	Ambient Rubber	Cryogenic Rubber
Operating Temperature	Ambient, max. 120° C	Below - 80° C
Size Reduction Principle	Cutting, tearing, shearing	Braking cryogenically embrittled rubber pieces
Particle Morphology	Spongy and rough, high specific surface	Even and smooth, low specific surface
Particle Size Distribution	Relatively narrow particle size distribution, only limited size reduction per grinding step	Wide particle size distribution (ranging 10 mm to 0.2 mm) in just one processing step
Maintenance cost	Higher	Lower
Electricity Consumption	Higher	Lower
LN2 Consumption	N/A	0.5 – 1.0 kgLN2 per kg tire input