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.

12. References

American Academy of Pediatrics (AAP). 2000. Climatic Heat Stress and the Exercising Child and Adolescent. *Pediatrics*, 106(1), 158-159.

Buskirk, E.R., McLaughlin, E.R., Loomis, J.L. 1971. Microclimate Over Artificial Turf. *Journal of Health, Physical Education, Recreation*. 42(9). November-December 1971, 29-30.

California Integrated Waste Management Board (CIWMB) 2007. Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products. Available online at: http://www.ciwmb.ca.gov/Publications/Tires/62206013.pdf [accessed 2/5/09].

DeVitt, D.A. Young, M.H. Baghzouz, M. Bird, B.M. 2007. Surface temperature, heat loading and spectral reflectance of artificial turfgrass. *Journal of Turfgrass and Sports Surface Science*, 83, 68-82.

Fisk, C. 2009. Graphical Climatology of New York Central Park Daily Temperatures, Precipitation, and Snowfall (1876-Present). Available online at: http://home.att.net/~ny_climo/ [accessed 4/1/09].

Fresenburg, B., & Adamson, C. 2005. Synthetic Turf Playing Fields Present Unique Dangers. Available online at: http://www.plantmanagementnetwork.org/pub/ats/news/2005/synthetic/ [accessed on 3/27/09].

Jia, X., Dukes, M.D., Miller, G.L. 2007. Temperature Increase on Synthetic Turfgrass. *Proceedings of the World Environment and Water Resources Congress 2007*

Katz, Abram 2007, New Haven Register 11/11/07. Artificial Turf Full of Toxins That Can Cause Cancer. Available online at: http://www.nhregister.com/articles/2007/11/11/import/19011749.txt [Accessed on 12/10/07].

Mattina, M.I., Isleyn, M., Berger, W., Ozdemir, S. 2007. Examination of Crumb Rubber Produced From Recycled Tires. Department of Analytical Chemistry the Connecticut Agricultural Experiment Station. Available online at: http://www.ct.gov/caes/lib/caes/documents/publications/fact_sheets/examinationofcrumbrubberac005.pdf [Accessed on 12/10/07].

National Federation of State High School Associations (NFSHSA) 2001. NFHS (National Federation High School) Sports Medicine Handbook. Available online at: http://www.miaa.net/sportsmedicine/NHFS/manual.pdf [accessed on 4/28/09].

National Oceanic and Atmospheric Administration (NOAA), National Weather Service . Heat Index. 2009. Available online at: http://www.crh.noaa.gov/jkl/?n=heat_index_calculator [accessed 3/31/09].

National Weather Service (NWS) Heat Index Program 2005. Available online at: http://www.nws.noaa.gov/om/brochures/heat_wave.shtml [accessed 2/10/09].

New Jersey Department of Environmental Protection (NJDEP) 2008. Guidance for the Determination of the Dilution-Attenuation Factor for the Impact to Ground Water Pathway. New Jersey Department of Environmental Protection. Site Remediation Program. June 2, 2008. Available online at: http://www.state.nj.us/dep/srp/guidance/rs/daf.pdf [accessed 2/9/09].

New York City Department of Health and Mental Hygiene (NYCDOHMH) 2008a. Report: Lead Hazard Risk Assessment of Synthetic Turf Playing Fields, March 2008. Available online at: http://www.precaution.org/lib/nyc_lead_risk_assessment.080415.pdf [accessed 2/4/09].

New York City Department of Health and Mental Hygiene (NYCDOHMH) 2008b. A Review of the Potential Heath and Safety Risks from Synthetic Turf Fields Containing Crumb Rubber Infill. Available online at: http://www.nyc.gov/html/doh/downloads/pdf/eode/turf_report_05-08.pdf [accessed 2/5/09].

New York State Department of Environmental Conservation (NYSDEC) 1998a. Division of Water Technical and Operational Guidance Series (1.1.1) Ambient Water Quality Standards and Guidance Values and Groundwater Effluent Limitations. Available online at: http://www.dec.ny.gov/docs/water_pdf/togs111.pdf [access 2/11/09].

New York State Department of Environmental Conservation (NYSDEC) 1998b. Ambient Water Quality Standards and Guidance Values and Groundwater Effluent Limitations. New York State Department of Environmental Conservation, Division of Water, 1998 Edition. Available online at: http://www.dec.ny.gov/regulations/2652.html

New York State Department of Environmental Conservation (NYSDEC) 1999. 6NYCRR Part 703: Surface Water and Groundwater Quality Standards and Groundwater Effluent Limitations. Available online at: http://www.dec.ny.gov/regs/4590.html [accessed 2/5/09].

New York State Department of Environmental Conservation (NYSDEC) 2006. 2006 Acid Deposition Executive Summary: New York State Acid Rain. Available online at: http://www.dec.ny.gov/chemical/29847.html [accessed 2/10/09].

New York State Department of Environmental Conservation (NYSDEC) Division of Solid & Hazardous Materials 2008. A Study to Assess Potential Environmental Impacts

From the Use of Crumb Rubber as Infill Material in Synthetic Turf Fields. July 17. Available online at:
http://www.dec.ny.gov/docs/materials_minerals_pdf/tirestudy.pdf [Accessed on 1/21/09].

New York State Department of Environmental Conservation (NYSDEC) and New York State Department of Health (NYSDOH) 2006. New York State Brownfield Cleanup Program Development of Soil Cleanup Objectives Technical Support Document. Available online at:
http://www.dec.ny.gov/docs/remediation_hudson_pdf/techsuppdoc.pdf [accessed 2/10/09].

New York State Department of Health (NYSDOH) Bureau of Toxic Substance Assessment 2008. Fact Sheet: Crumb-Rubber Infilled Synthetic Turf Athletic Fields. August 2008. Available online at:
http://www.health.state.ny.us/environmental/outdoors/synthetic_turf/crumb-rubber_infilled/fact_sheet.htm [Accessed on 1/21/09].

Northeast Regional Climate Center (NRCC) 2000. Normal precipitation 1961 – 1990. Available online at: http://met-www.cit.cornell.edu/ccd/nrmpcp.html [accessed 2/2/09] *note: the station in New York City's Central Park was selected for the rainfall total used in this study.*

Norwegian Institute for Air Research (NILU) 2006. Measurements of Air Pollution in Indoor Synthetic Turf Halls. NILU OR 03/2006. Kjeller, Norway.

Norwegian Institute of Public Health and the Radium Hospital (NIPHRH) 2006. Artificial turf pitches – an assessment of the health risks for football players. Oslo, Norway. January 2006.

R.W.(Beck), Inc. 2006. Final Report Analysis of New York Scrap Tire Markets: 2006 Update. Prepared for New York State Department of Economic Development. Available online at:
http://www.nylovesbiz.com/pdf/polution_prevention_recycle/tires_update2006.pdf [Accessed on 2/5/09].

Rochesterians Against the Misuse of Pesticides (RAMP) 2007. Synthetic Turf Chemicals. Available online at: http://www.albany.edu/ihe/SyntheticTurfChemicalsdar.htm [Accessed on 12/10/07].

Serkiz, S.M., Knaub D., Lee C. 1999. Phase II Nuclide Partition and Laboratory Study Influence of Cellulose Degradation Products on the Transport of Nuclides from SRS Shallow Land Burial Facilities. Department of Energy Report WSRC-TR-99-00298, pp 15-56. Available online at:
http://www.osti.gov/energycitations/servlets/purl/13808-FraNpD/webviewable/ [accessed 1/30/09].

Steadman, R.G. 1979a. The Assessment of Sultriness. Part I: A Temperature-Humidity Index Based on Human Physiology and Clothing Science. *Journal of Applied Meteorology*. 18, 861-873.

Steadman, R.G. 1979b. The Assessment of Sultriness. Part II: Effects of Wind, Extra Radiation and Barometric Pressure on Apparent Temperature. *Journal of Applied Meteorology.* 18, 874-885.

Snyder, R. H. (1998), "Scrap Tires: Disposal and Reuse", Society of Automotive Engineers, Inc., Warrendale, PA.

United States Department of Housing and Urban Development (HUD) 1995. Guidelines for the Evaluation and Control of Lead-based Paint Hazards in Housing. Available online at: http://www.hud.gov/offices/lead/lbp/hudguidelines/index.cfm [Accessed on 3/30/09].

United States Environmental Protection Agency (USEPA). 1989. Risk Assessment Guidance for Superfund. Volume I. Human Health Evaluation Manual Part A. Washington DC: US EPA Office of Emergency and Remedial Response. EPA/540/1-89/002

United States Environmental Protection Agency (USEPA) 1996a. Method 6010B - Inductively Coupled Plasma-Atomic Emission Spectrometry. Available online at: http://www.epa.gov/region8/water/biosolids/biosolidsdown/methods/6010b.pdf [accessed 2/4/09].

United States Environmental Protection Agency (USEPA) 1996b. Soil Screening Guidance: User's Guide, Second Edition. United States Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington DC 20460, July 1996. Available online at: http://www.epa.gov/superfund/health/conmedia/soil/index.htm#user [accessed 2/9/09].

United States Environmental Protection Agency (USEPA) 1999a. Contract Laboratory Program National Functional Guidelines, For Organic Data Review. Available online at: http://www.epa.gov/superfund/programs/clp/download/fgorg.pdf [Accessed on 1/29/08].

United States Environmental Protection Agency (USEPA) 1999b. US EPA Contract Laboratory Program National Functional Guidelines for Organic Data Review. Washington DC: Office of Emergency and Remedial Response. OSWER 9240.1-05A-P. EPA540/R-99/008.

United States Environmental Protection Agency (USEPA) 2001. Lead: Identification of Dangerous Levels of Lead; Final Rule. Federal Register. 66:1206-1240.

United States Environmental Protection Agency (USEPA) 2002. A Review of the Reference Dose and Reference Concentration Process. Final Report. EPA/630/P-02/002F. Washington, DC: Risk Assessment Forum.

United States Environmental Protection Agency (USEPA) 2004. Contract Laboratory Program National Functional Guidelines, For Inorganic Data Review. Available online at: http://www.epa.gov/superfund/programs/clp/download/inorgfg10-08-04.pdf [accessed 2/5/09].

United States Environmental Protection Agency (USEPA) 2009a. Test Methods for Evaluating Solid Waste, Physical/Chemical Methods (SW-846). Available online at: http://www.epa.gov/epawaste/hazard/testmethods/sw846/index.htm [accessed 1/30/09].

United States Environmental Protection Agency (USEPA) 2009b. Air Toxic Methods. Available online at: http://www.epa.gov/ttn/amtic/airtox.html [accessed 3/30/09].

Williams, T.B., 1991. Microclimate Temperature Relationships over Different Surfaces. Journal of Geography. November/December 1991.

Williams, C.F. & Pulley, G. E. 2006. Synthetic surface heat studies. Brigham Young University. Available: http://cahe.nmsu.edu/programs/turf/documents/brigham-young-study.pdf [accessed 1/15/09].

Zhang, J., Han, I., Zhang, L., Crain, W. 2008. Hazardous chemicals in synthetic turf materials and their bioaccessibility in digestive fluids. Journal of Exposure Science and Environmental Epidemiology, 18, 600-607.

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

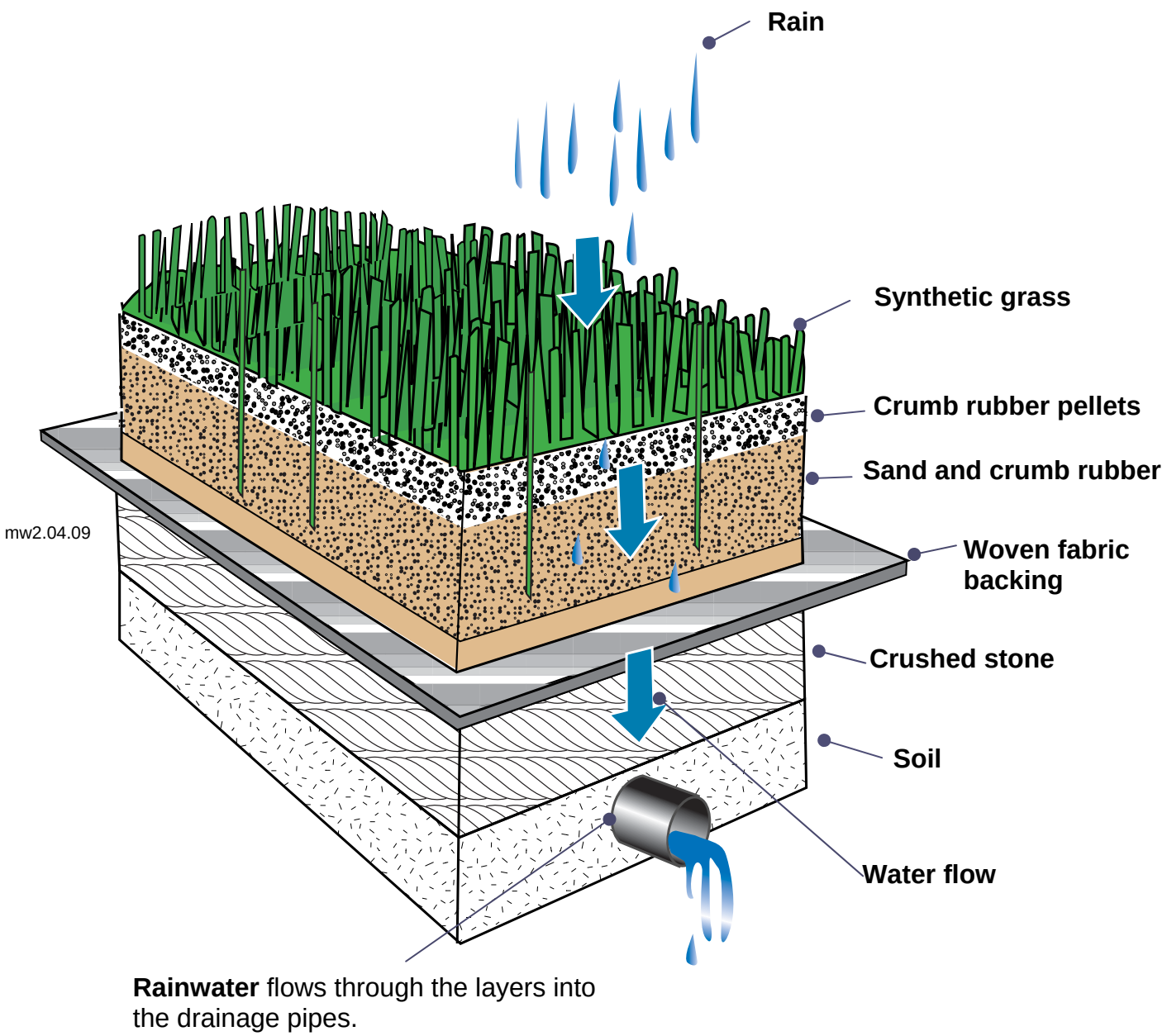

Figure 1.1 Cross-section of a typical synthetic turf field configuration

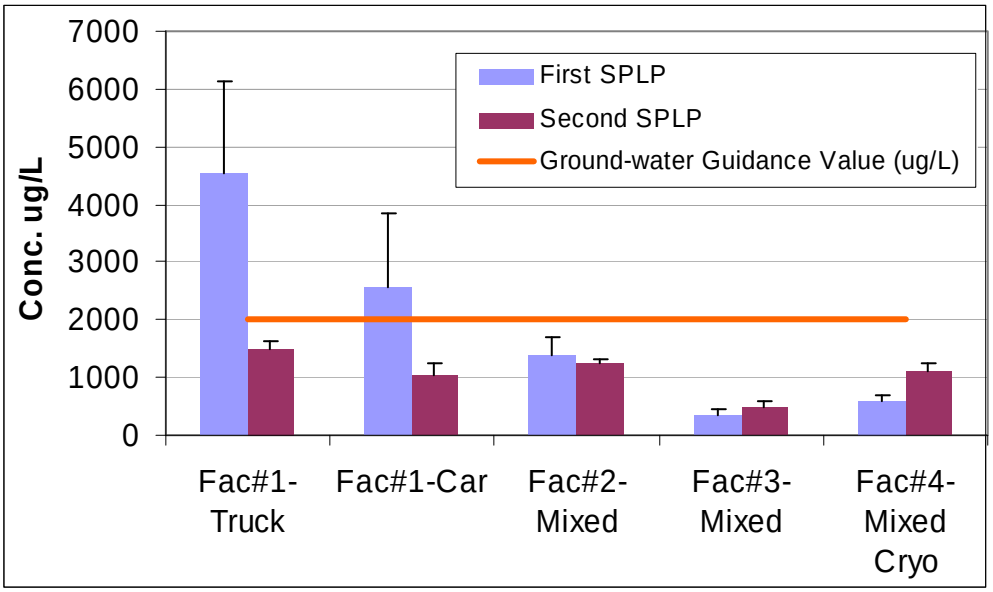

Figure 2.1 Zinc concentration in SPLP tests

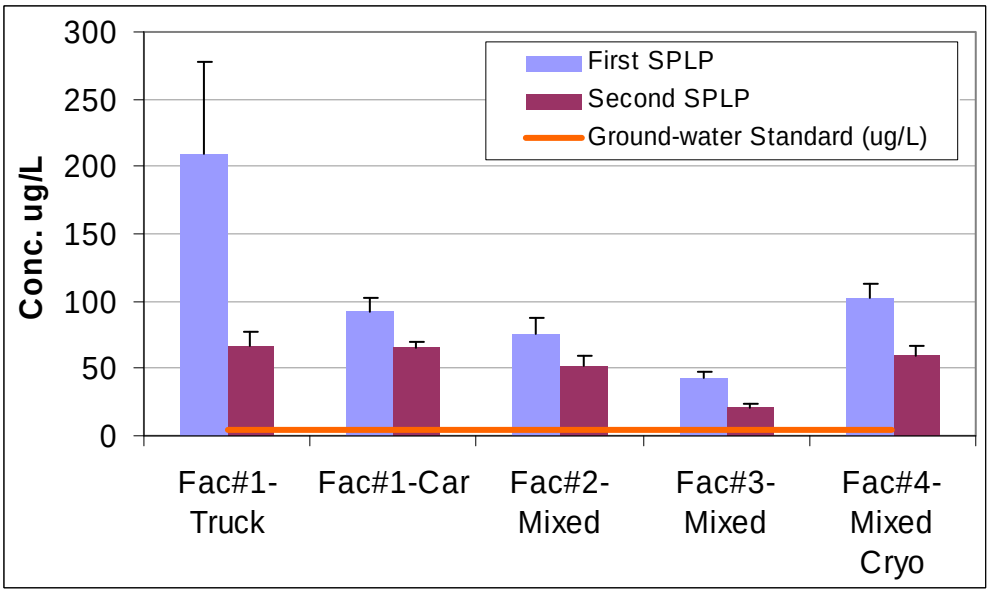

Figure 2.2 Aniline concentration in SPLP leachate

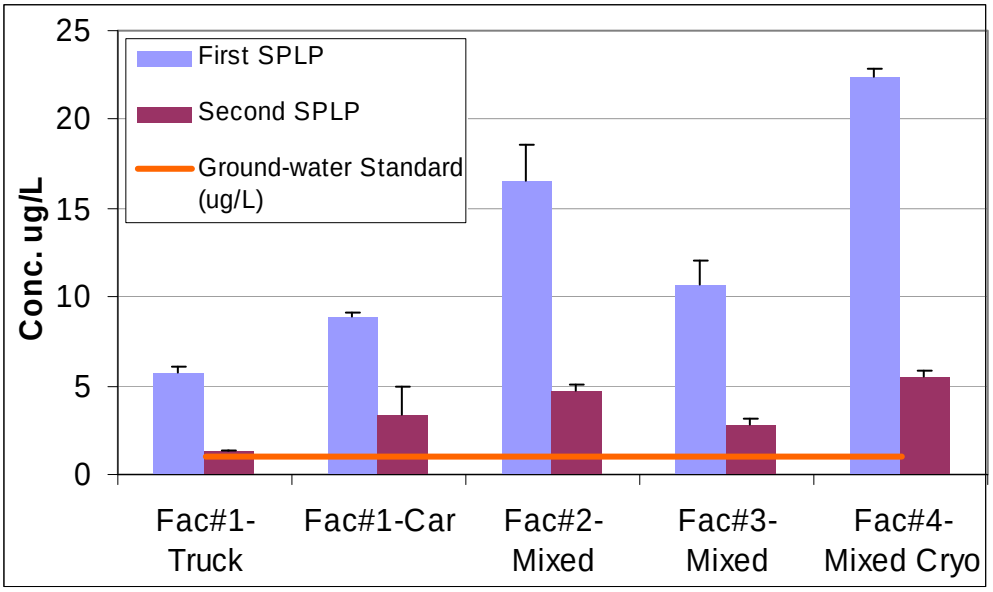

Figure 2.3 Phenol concentration in SPLP leachate

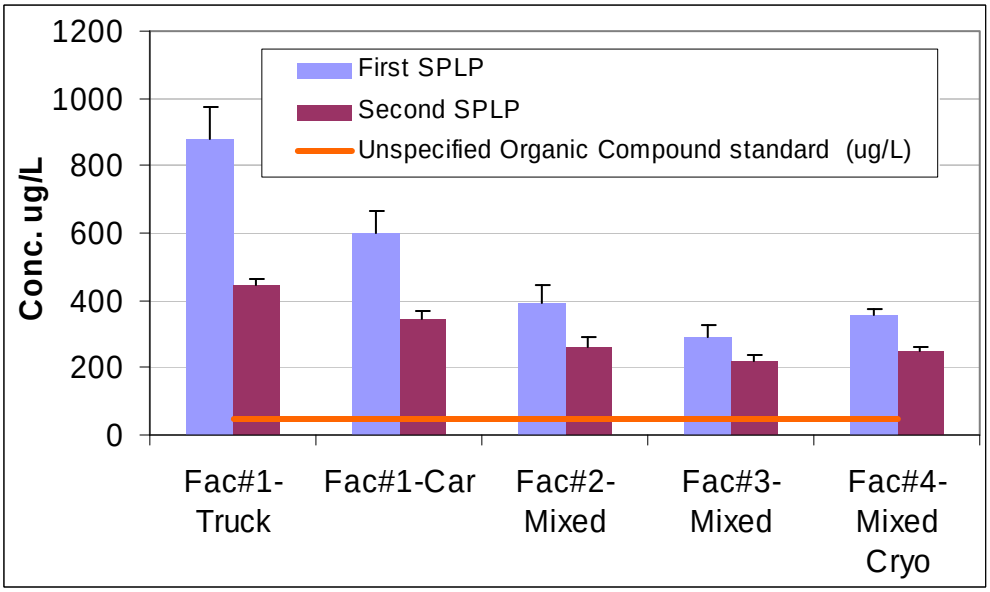

Figure 2.4 Benzothiazole in SPLP leachate

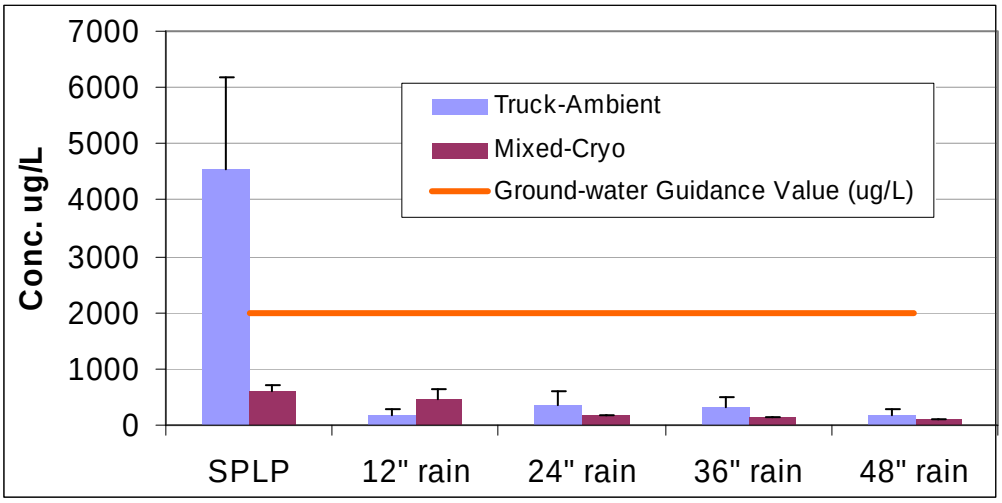

Figure 3.1 Comparison of zinc levels between SPLP and column tests

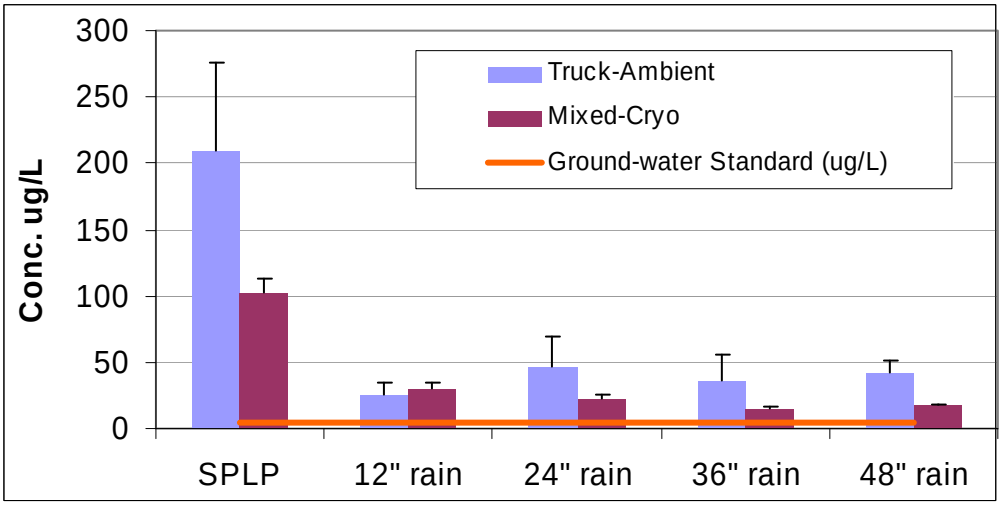

Figure 3.2 Comparison of aniline levels between SPLP and column tests

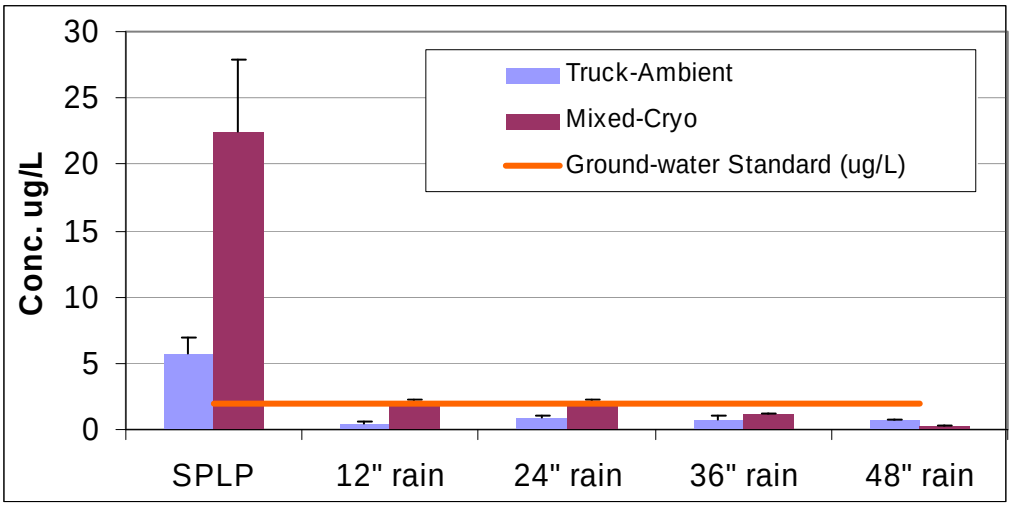

Figure 3.3 Comparison of phenol levels between SPLP and column tests

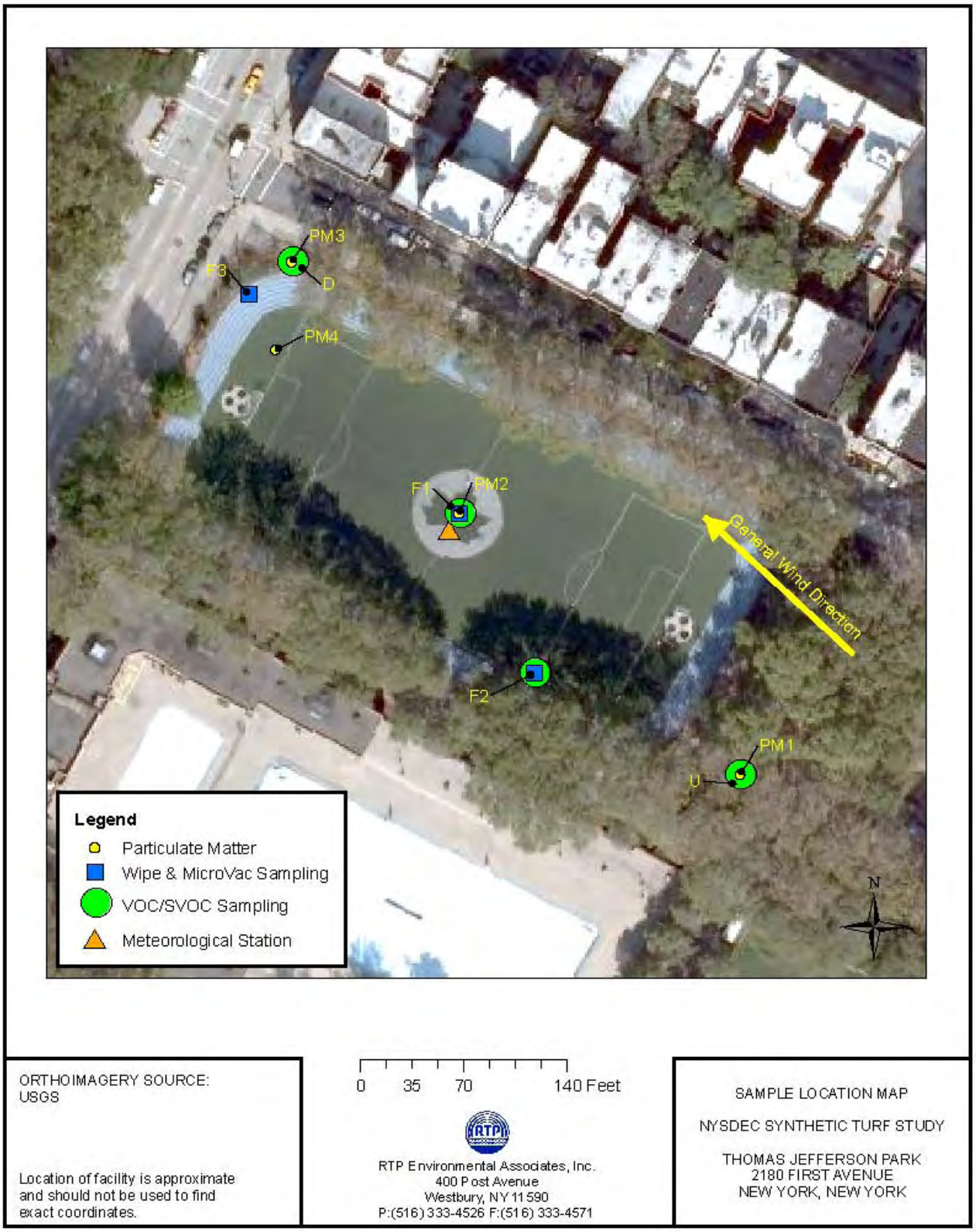

Figure 7.1 Thomas Jefferson Park Sampling Locations

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

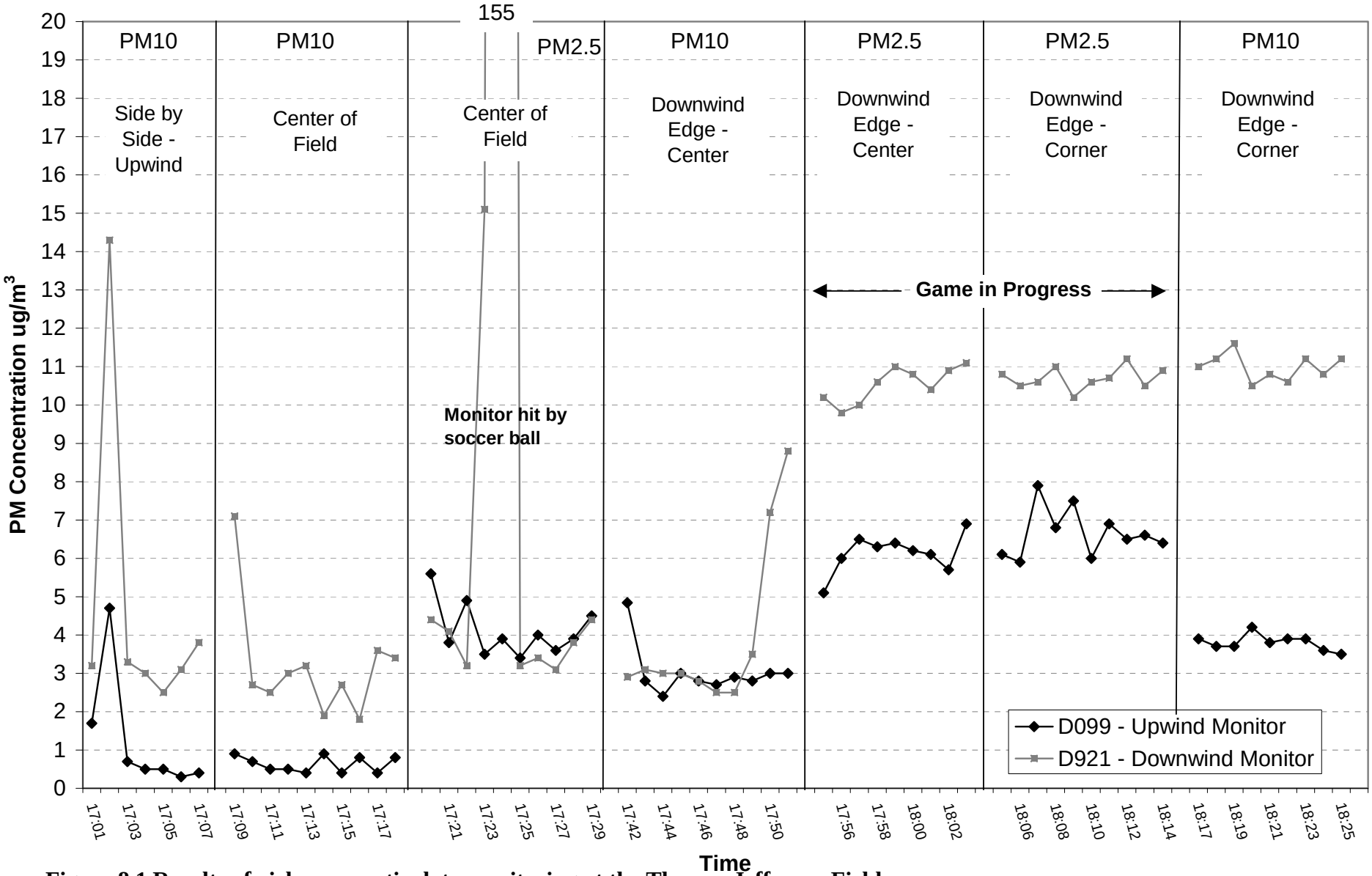

Figure 8.1 Results of airborne particulate monitoring at the Thomas Jefferson Field

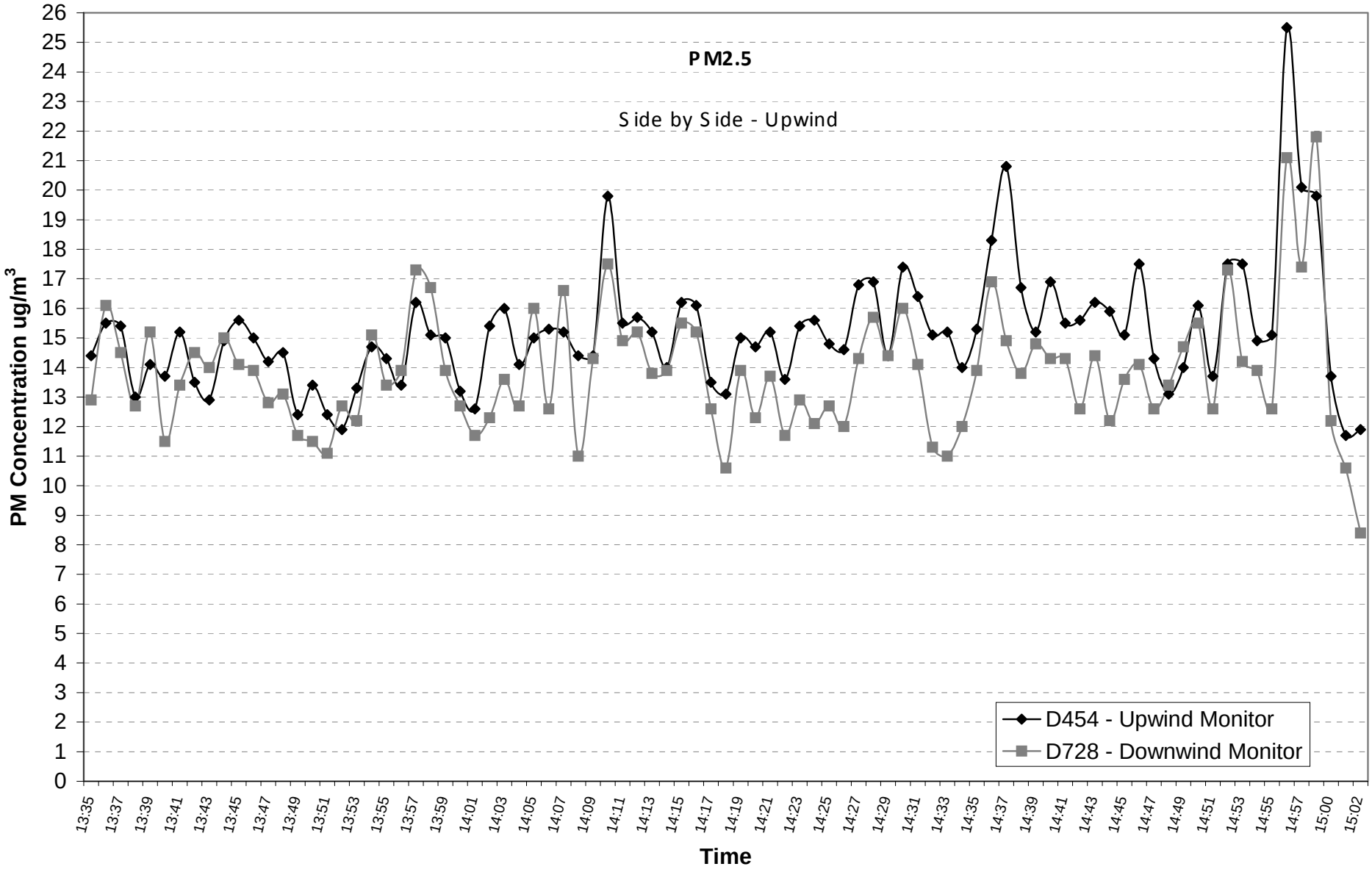

Figure 8.2 Results of side by side monitoring for airborne particulate monitoring at the upwind location on the John Mullaly Field

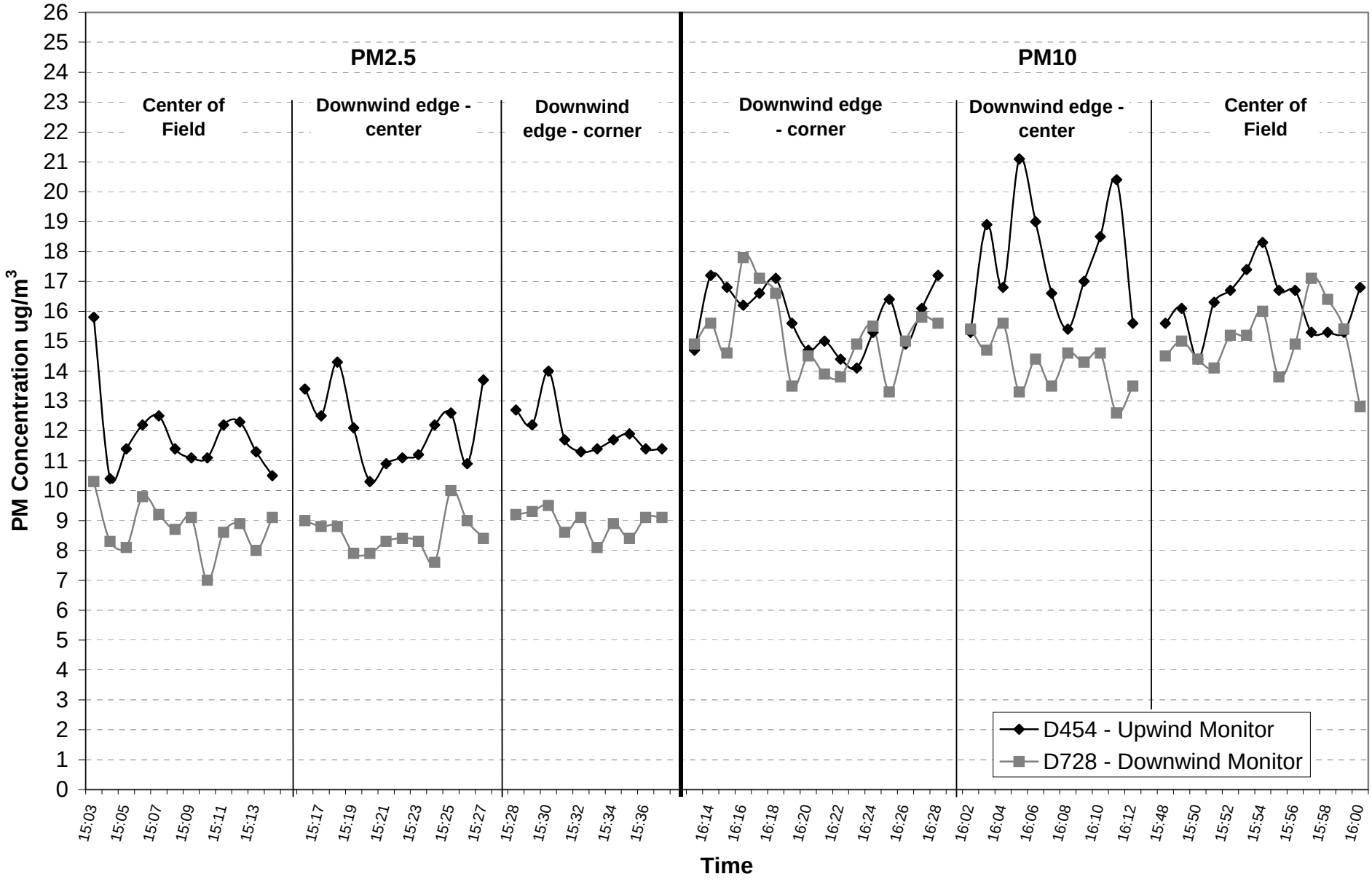

Figure 8.3 Results of airborne particulate monitoring at the John Mullaly Field

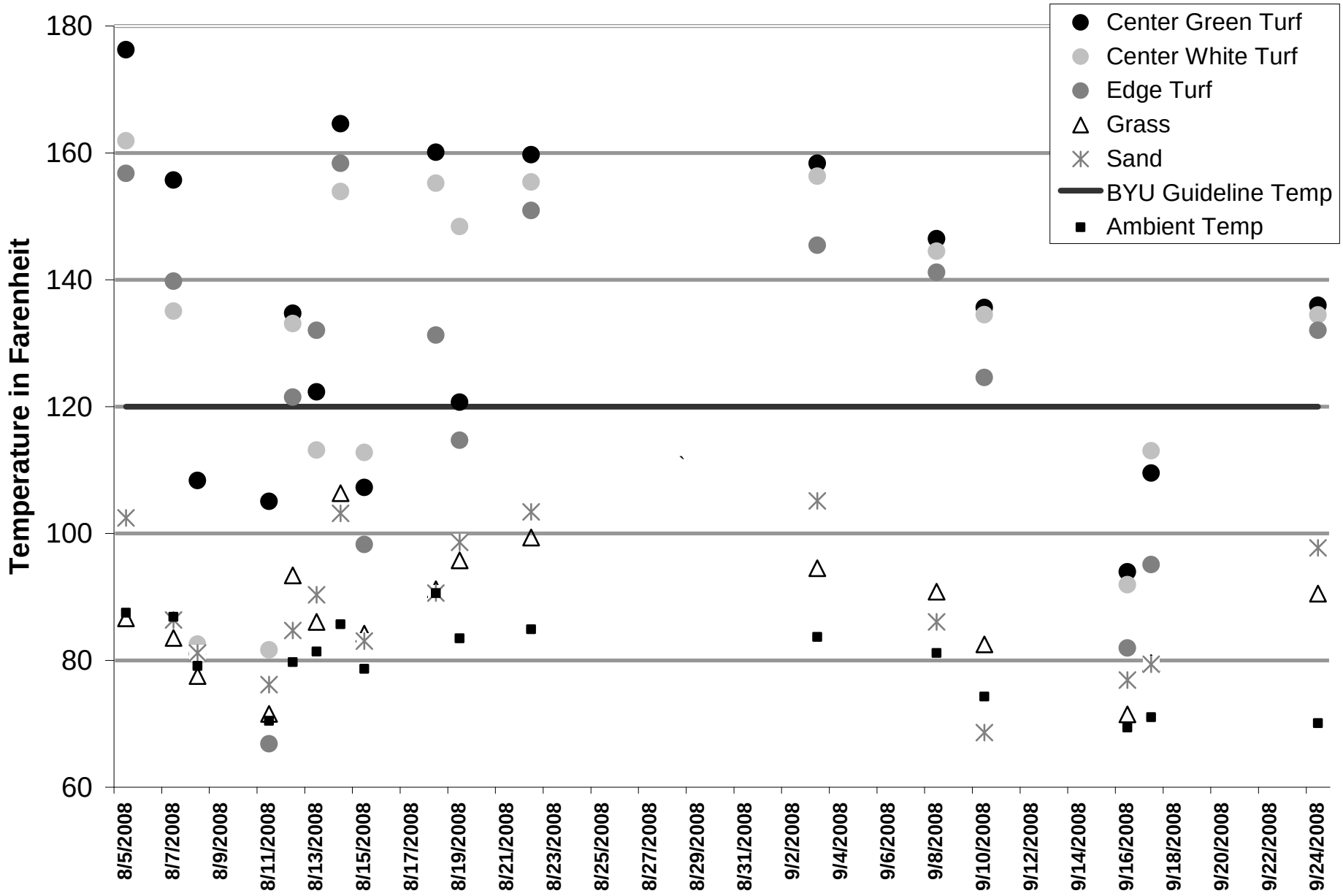

Figure 9.1 Thomas Jefferson field surface temperature measurements by date

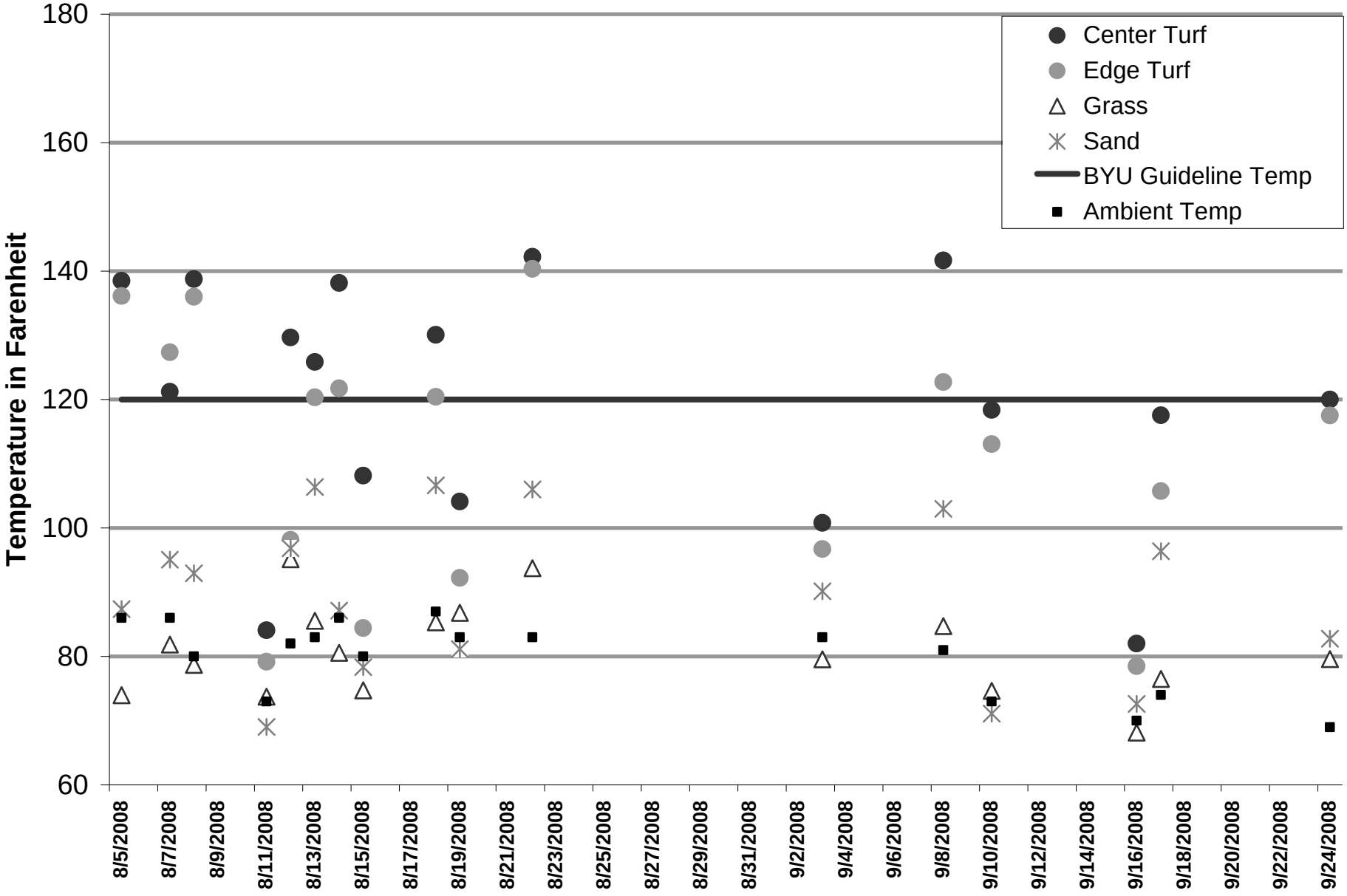

Figure 9.2 John Mullaly field surface temperature measurements by date

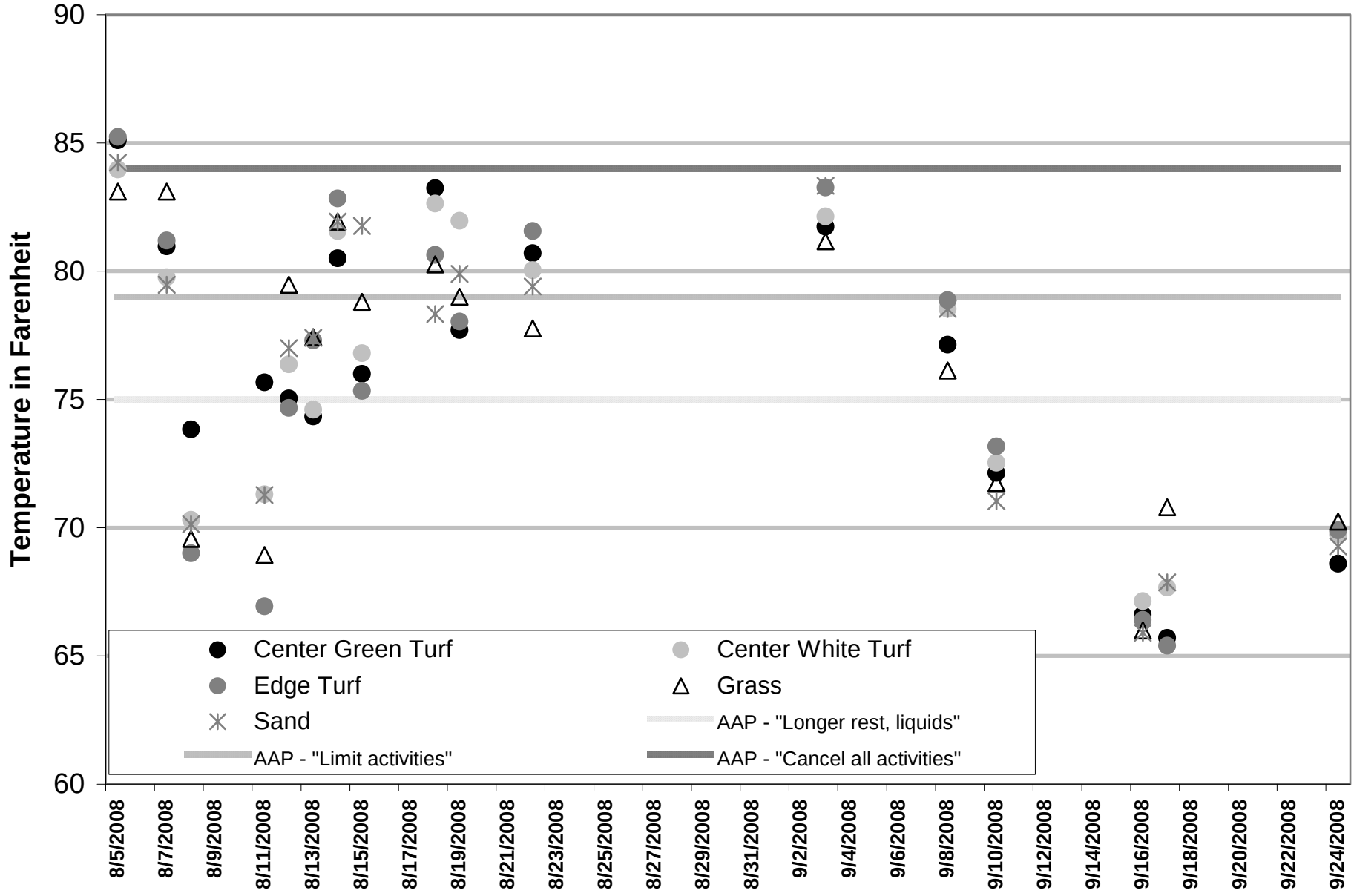

Figure 9.3 Thomas Jefferson field wet bulb globe temperatures by date

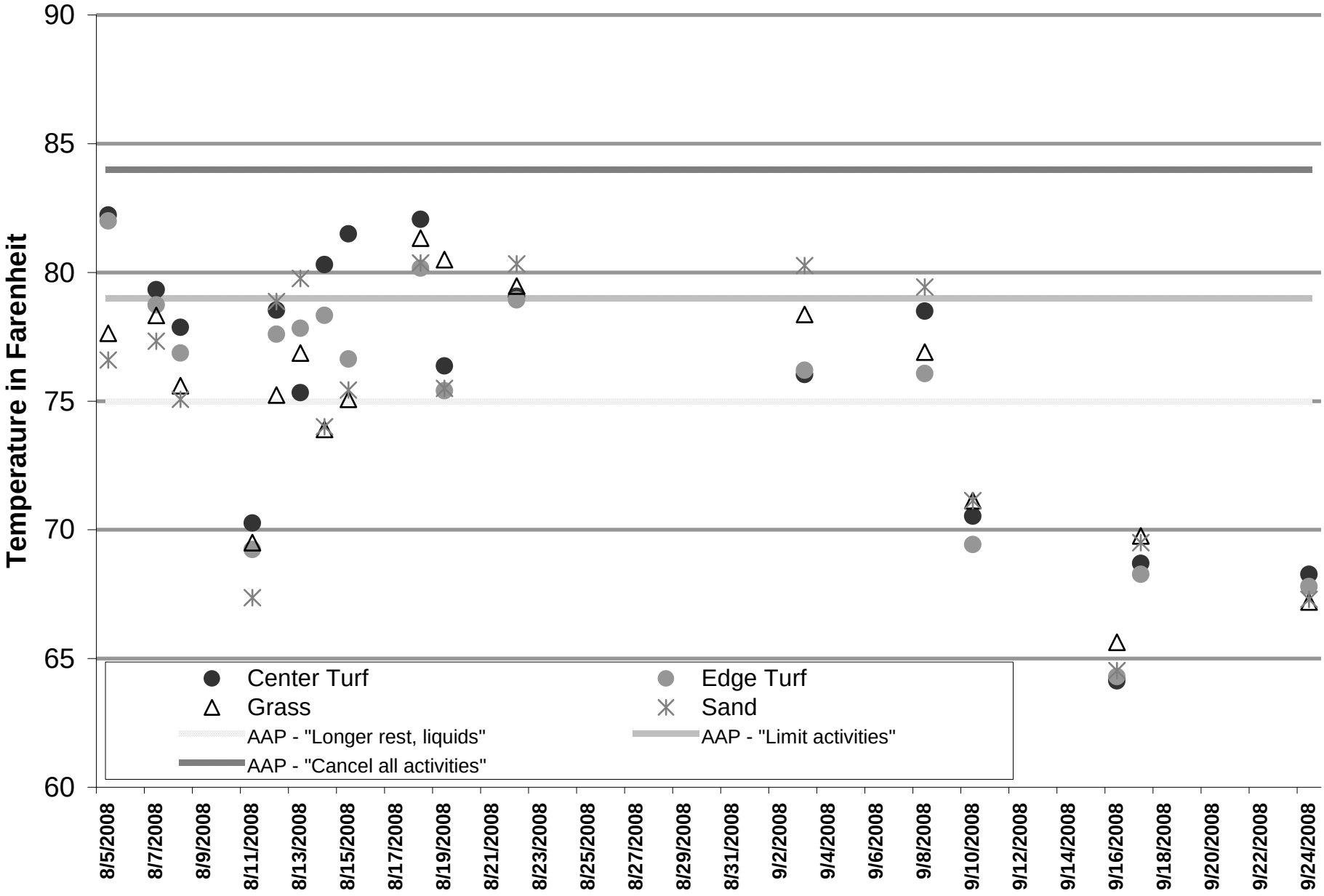

Figure 9.4 John Mullaly field wet bulb globe temperatures by date