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Technical Memorandum

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Subject: **Synthetic turf impacts on storm water and flood resilience, and potential for heat island and heat-stress effects**

The Division of Science and Research (DSR) was asked by the Green Acres Program to review and provide a summary of 1) the potential impacts of synthetic turf fields on storm water and flood resilience and 2) the potential heat impacts to users of these fields. With respect to part 2, it was asked that DSR consider impacts from an urban community and environmental justice perspective to determine if playing on these fields contributes more to increased risk to factors like heat exhaustion than from playing on natural grass.

Briefly, current scientific information demonstrates that there is support for the installation of synthetic turf fields when the proper construction and design measures include sufficient drainage systems to manage stormwater retention. While synthetic turf fields can be designed to accommodate extreme rainfall events, these fields may be severely damaged during flooding and infill material may be washed away and enter the environment. With regards to heat and synthetic turf, individuals on or near synthetic fields on a sunny day will be exposed to hotter temperatures than predicted by local ambient measurements, and therefore may be at a greater risk of heat-illness. Precaution should be made to avoid extended strenuous exercise on synthetic turf fields on hot sunny days (e.g., summer months). Finally, while a relatively low contributor in comparison, synthetic turf fields will add to the cumulative impacts of built urban environmental features (e.g.. buildings, paved roads, etc.) that contribute to the urban heat island effect. However, individuals in close proximity to the synthetic turf fields will experience hotter temperatures than they would otherwise from a natural grass field. The following reviews and summarizes the information used to draw these conclusions.

Part 1: Potential impacts of synthetic turf fields on storm water and flood resilience

The use of synthetic turf has become popular in fields that are used frequently and year-round, especially when maintenance costs and soil compaction make the use of natural grass fields impractical (NYCDPR, 2010). It has been argued that these field are easily maintained by custodial staff while providing a variety of uses to the community (Klifman, 2014). However, damaged synthetic turf fields are difficult to repair and may require complete replacement, which may include high up-front installation costs. The materials used to make synthetic turf fields typically are not recyclable and will need to be disposed of properly. In addition to increased access for users, the drainage capacity of well-designed and maintained synthetic turf fields can be leveraged to improve stormwater management practices (Hudepohl et al., 2016; Lozano & Ferguson, 2021; NYCDPR, 2010; Synthetic Playfields Task Force, n.d.). This section will provide an overview of the potential for stormwater management and flood resilience associated with synthetic turf fields.

Stormwater considerations:
There is support for the installation of synthetic turf fields when the proper construction and design measures include sufficient drainage systems to manage stormwater retention. Because these fields are of significant size and their construction necessitates clearing of the land and compacting the soil, they cease to function as pervious cover and thus must be designed to store and slowly diffuse stormwater. Typical synthetic turf fields are composed of porous layers and built-in drainage systems designed to allow for water penetration and minimal runoff (Lozano & Ferguson, 2021). Proper drainage design, with subsurface storage capacity, can thus be leveraged to manage stormwater runoff and reduce peak flow (Hudepohl et al., 2016). Some manufacturers claim that the drainage capacity of synthetic turf fields is higher than that of natural grass (Cheng et al., 2014; Synthetic Turf Council, 2011). However, there is at least one recent experimental study showing that natural grass outperforms synthetic grass in runoff reduction and water retention (Simpson & Francis, 2021). Ultimately, proper drainage of synthetic grass fields goes beyond the turf's infiltration capacity. The successful installation of a well-draining turf field requires the sub-base material to also drain well. Therefore, care should be taken when assessing the permeability of soils/materials present in the installation (Synthetic Grass Warehouse, n.d.).

Synthetic turf fields with proper drainage systems can be a good choice for areas where natural grass fields are not practical due to cost of maintenance and where there is a very high demand for usage. There is potential, if designed, constructed, and maintained properly, for these fields to be able to retain and slowly release high volumes of precipitation and storm water. Maintenance is essential to proper hydrologic functioning. If maintenance costs are burdensome, there is greater potential for these fields and the retention and drainage components to fail. The New York City Department of Parks and Recreation (NYCDPR, 2017) suggests it is best practice not to install synthetic turf fields near or within the 100-year flood zone and areas adjacent to open ocean that are vulnerable to high velocity wave action and storm surge. Furthermore, they suggest that in-fill type field not be installed in areas where standing water may frequently occur.

Flooding considerations:
While synthetic turf fields can be designed to accommodate extreme rainfall events, these fields may be severely damaged during flooding. The New York City Department of Parks and

Recreation (NYCDPR, 2017) and the San Francisco Recreation and Parks Department (Synthetic Playfields Task Force, n.d.) both suggest that synthetic turf fields not be installed in areas prone to flooding. Synthetic turf with pelletized infill, as opposed to carpet-style, is particularly vulnerable to flooding, since the infill material may become negatively buoyant and wash away (NYCDPR, 2017). If the infill type is selected for installation in areas that commonly experience flooding, preference should be given to infill materials with high specific gravity since these are less likely to wash away (Sportsfield Management, 2018).

Of importance, is the fact that some synthetic turf fields are designed to include small, rubberized pellets that are buoyant and mobile. A significant source of this infill material is recycled rubber, primarily from used tires. If installation fails to produce a well-draining field, material losses, especially of pelletized infill, can be significant. It is possible for these pellets to break into smaller pieces. Particles of this nature less than 5 mm are considered microplastics (Li, 2019; Lozano & Ferguson, 2021). These particles are transported off site to the nearest stream during heavy rains and flooding conditions above those in the construction design. The presence of the infill material in the aquatic systems can be characterized as an environmental and ecological contaminant, which will pose additional environmental and health impacts (Cheng et al., 2014; Li, 2019; Lozano & Ferguson, 2021).

NJDEP Rules:
Synthetic turfs fields are not regulated by name under NJDEP rules. They are, however, subject to the same review and considerations as any other development project under the Stormwater Rules (NJAC 7:8). Under the stormwater rules, construction of this type of field would be considered a major development as soccer fields, for example, generally are greater in size than 1 acre. Therefore, installation of these fields falls under regulations as outlined in NJAC 7:8 and must adequately provide for erosion control, groundwater recharge, stormwater runoff quantity control, and stormwater runoff quality treatment. The storm size needed to be accommodated varies depending on the regulated control but includes designing up to the 100 year 24-hr storm for stormwater runoff quantity control.

Synthetic turf fields are also subject to other rules and regulations including the Flood Hazard Area Rules (NJAC 7:13), which includes riparian zone requirements in addition to flood hazard requirements; Coastal Zone Management Rules (NJAC 7:7), which includes Waterfront Development, CAFRA, and Coastal Wetlands; and the Freshwater Wetlands Protection Act Rules (NJAC 7:7A), which regulate impacts to freshwater wetlands and buffers surrounding those wetlands. It is expected that rule updates envisioned under New Jersey Protecting Against Climate Threats (NJPACT) will incorporate both sea level rise and future precipitation intensity totals to inform design standards used as the basis for development.

If designed in compliance with Department rules and regulations, these fields should retain and control associated stormwater and runoff that would otherwise infiltrate to the groundwater and should not increase local flooding potential. Proper maintenance is essential to maintaining the hydrologic integrity.

Part 2: Potential heat impacts to users of these fields

Literature Review:

This review is based in part on literature obtained from searches initiated in February 2022 by the Environmental Research Library on various databases (PubMed, Google Scholar, State Library) for articles discussing synthetic turf and possible heat-related effects on human health. Additional searches continued through May 2022 to obtain updated materials. In addition to peer-reviewed literature, state and local government documents, and documents from the federal government (USEPA) were reviewed. Articles that were older than 1990 were excluded given that synthetic turf technology has undergone several evolutions (Jastifer et al., 2019), and only research related to later generation synthetic turf was considered relevant.

Background:

Synthetic turf is often employed on grounds with high volume of play because of the long-term durability, ease of maintenance, and cost benefit (Jastifer et al., 2019; Yurgil et al., 2021). Previous field- and literature-based research efforts by DSR on human health and synthetic turf fields have focused primarily on the risks associated with exposure to substances, such as metals, organic compounds, and polycyclic aromatic hydrocarbons, from the recycled tires used to compose the crumb rubber infill (Lioy & Weisel, 2011; NJDEP, 2011, 2020). Overall, the studies and reports found that the toxic substances present in synthetic turf fields occur at such low concentrations that human exposure, and therefore the risk, is minimal.

A significant disadvantage, however, to using synthetic turf for playing fields is the fact that they heat up at the surface when exposed to direct sunshine and can also heat up the surrounding area. Surface temperatures of synthetic turf are influenced by weather variables including ambient temperature, relative humidity, wind, and cloud cover (Jim, 2017; Petrass et al., 2014). This elevation in surface temperature is specifically due to the high solar absorption and the lack of evaporative cooling, which normally occurs with natural turf (Tebakari et al., 2010; Yaghoobian et al., 2010). Numerous studies have reported that surface temperatures of synthetic turf can be significantly hotter than the surrounding air temperature (Claudio, 2008; Grundstein & Cooper, 2020; Jim, 2017; Thoms et al., 2014). In addition to weather variables, the increase in temperature also appears to be dependent on the compositions of the turf, and specifically, the fibers rather than on the infill crumble (Thoms et al., 2014), and color as well (Williams & Pulley, 2002). For example, the thermoplastic rubber and monofilament fibers of the third-generation synthetic turf appear cooler than the styrene–butadiene rubber and fibrillated fibers of older generations, particularly as the turf ages (Villacañas et al., 2016). In a comparison of 10 different synthetic turf products by researchers at Penn State University, the surface temperature exceeded the air temperature (taken at 3 feet above the ground) by anywhere from approximately 23-32°C (41-59°F) depending on the month the measurements were taken (McNitt & Petrunak, 2022). On a sunny day, synthetic turf surface have been shown to heat to nearly 40°C (72°F) degrees above that of natural turf (Jim, 2017).

Synthetic Turf and Urban Heat Island Effects:

One concern brought about by the increased surface level temperatures of synthetic turf is the potential to contribute to urban heat island effects. While synthetic turf has repeatedly and consistently been shown to have higher temperatures than natural grass and asphalt playing surfaces (McNitt & Petrunak, 2022; NYSDEC, 2009; Petrass et al., 2014), its contribution to the overall urban heat island effects is complicated. Solar energy enters our atmosphere as shortwave radiation (UV), which is absorbed by the Earth's surface and then re-emitted as longwave radiation (infrared rays). Buildings absorb heat from direct solar radiation, but also from the surrounding ground level material (radiative heat transfer), such that the sum of the reflected solar shortwave and the emitted longwave influence the building wall heat fluxes. Yaghoobian et al. (2010) modeled radiation, convection, and conduction of synthetic turf, concrete, asphalt, and natural grass, and found that while synthetic turf re-emitted the largest net longwaves (in other words, put off more heat) it also reflected the least shortwaves, making its net contribution to radiative heat transfer nearly equal to that of grass. In addition, surface temperatures of synthetic turf can be approximately 2°C (3.6°F) lower than that of natural grass during nighttime, suggesting it may act to mitigate hot, humid nights (Tebakari et al., 2010). Synthetic turf also cools more quickly in the afternoon than natural turf, even on days where it exceeds heat-stress thresholds for extended periods, and cools faster on cloudy/partial sunny days (Jim, 2017).

The ability to dissipate heat rapidly once the sun goes down and the observation that synthetic turf systems absorb more radiant heat away from surrounding buildings than natural turf and asphalt may appear as positive qualities in an urban environment. However, on sunny days, synthetic turf makes the immediate environment hotter than ambient temperatures, which is both uncomfortable and potentially dangerous for anyone in contact with the field, including athletes and players (Abraham, 2019).

Synthetic Turf and Heat-Stress:
Elevated surface temperatures of synthetic turf may result in a variety of heat-related injuries. There are at least two widely known anecdotal cases of individuals who have been physically burned by hot synthetic turf heated by the sun. The first was of a football coach at Brigham Young University following a practice (Williams & Pulley, 2002) and the second was of six Peruvian soccer players having burns and blisters on their feet as a result of playing on synthetic turf fields (Arce, 2007). However, the more pressing concern is that of heat-stress from exercising in an unusually hot environment. When humans are exposed to elevated temperatures for an extended period, they may experience adverse heat related effects, including heat exhaustion, heat-stress, and heat stroke. According to the American College of Sports Medicine, clinically, there is little difference between an athlete experiencing exhaustion following a difficult workout in cool conditions verses someone who collapses in hot weather with a limited workout (Armstrong et al., 2007). The time to exhaustion from heat-stress decreases as the ambient temperature goes above 20°C (68°F). People experience longer heat-stress duration while exercising on synthetic turf than comparable physical activity on natural turf (Liu & Jim, 2021). Every year, multiple heat-related deaths occur in athletes that are otherwise at the pinnacle of health and physical fitness, particularly in sports such as American Football and Soccer (Schultz et al., 2014) – both commonly played on synthetic turf.

Children are widely regarded as more sensitive than adults to extreme heat conditions because children have a higher surface area to mass ratio, higher metabolic rate, higher skin temperature, and are less efficient at evaporative cooling (Falk & Dotan, 2008; Liu & Jim, 2021; NYCDHMH, 2008). Children are generally not as adept at perceiving “thermal discomfort,” and therefore may not undergo the appropriate behavioral adaptations to avoid over-heating (Vanos, 2015). Additionally, due to children's shorter stature, a greater proportion of their body is at closer proximity to the surface, potentially increasing the risk to heat impacts from the effect of synthetic turf's radiative heat transfer. Children are also at greater risk of experiencing a burn-related injury as they are more likely to be in greater contact with the synthetic turf surface than adults (NYCDHMH, 2008).

The American Academy of Pediatrics (AAP) issued a policy on climatic heat-stress and exercise for children that says “Exercise, sport participation, and other physical activity should be modified for safety in relation to the degree of environmental heat-stress: air temperature, humidity, and solar radiation, as indicated by the heat index or wet-bulb globe temperature (WBGT)[1], for those with access to such a device,” (McCambridge et al., 2011). The National Athletic Trainers’ Association also recommends that WBGT be used in lieu of ambient air temperature to determine if athletic events should be canceled for the day (Casa et al., 2015). Pryor et al. (2017) found that local National Weather Service WBGT was inadequate at measuring the WBGT at a specific athletic field location, as their data identified a wide range of WBGT among various athletic surfaces, including different types of synthetic turf. Therefore, understanding the exact environmental conditions for a specific field location is critical to protect field users from an unsafe environment.

Minimizing overheating and dehydration are key to avoiding heat-stress related injury. Studies have shown that implementing shade into the built environment and shade from tree canopies are the most promising mitigation techniques to reduce child burns, increase park usability, and mitigate urban heating (Antoniadis et al., 2018; Vanos et al., 2016). Synthetic turf fields are traditionally used as large open sports fields with minimal shade. Water irrigation has been demonstrated to effectively reduce the surface temperature of infill systems, but only for a limited period of time (McNitt et al., 2008; Williams & Pulley, 2002). Ultimately, the risk of heat-stress associated with synthetic turf is largely dependent on how aware supervising adults are of the temperature concerns, and whether appropriate mitigation efforts are enacted (Jastifer et al., 2019).

Government Agency Reports on Health Effects of Synthetic Turf:
There is currently a multiagency research effort involving the Centers for Disease Control and Prevention/Agency for Toxic Substances and Disease Registry (CDC/ATSDR), the U.S. Environmental Protection Agency (USEPA), and the Consumer Product Safety Commission

[1] WetBulb Globe Temperature (WBGT) is a measurement of temperature, humidity, wind speed, sun angle, and cloud cover to assess heat-stress in direct sunlight, as opposed to the heat index, which is calculated for shaded locations and considers only temperature and humidity. Nat Weather Service: https://www.weather.gov/tsa/wbgt

(CPSC) investigating concerns of potential health risks from playing on synthetic turf[2]. However, this effort is largely focused on exposure to the contaminants in the tire crumb rubber infill and not on heat-related effects. Similarly, the Connecticut Department of Energy and Environmental Protection (CTDEEP), in conjunction with University of Connecticut Health Center (UCHC), the Connecticut Agricultural Experiment Station (CAES), and the Connecticut Department of Public Health (CTDPH), conducted a two-year evaluation of synthetic turf fields that was largely focused on the effects of the chemical composition and off-gassing of the synthetic turf (CAES, 2010; CTDEP, 2010; CTDPH, 2010; UCHC, 2010). New York State Department of Environmental Conservation (NYSDEC) also largely focused on chemical exposures (e.g., lead-based pigments in fibers) in their assessment of synthetic turf fields, but also included a temperature survey to assess the surface temperature of synthetic turf fields and the potential for heat-related sickness among field users (NYSDEC, 2009). The NYSDEC study found that surface temperatures of synthetic turf were on average 2-6°C (35-42°F) higher compared to natural turf, but temperatures as high as 25.5°C (78°F) were also recorded. These temperatures exceeded heat indices used by the National Weather Service to determine the potential for heat-stress (NYSDEC, 2009).

The New York City Department of Health and Mental Hygiene (NYCDHMH) reviewed the potential health and safety risks of synthetic turf, including temperature related concerns. While the NYCDHMH report suggests that synthetic turf fields may contribute to the urban heat island effect, it is small in comparison to the contribution of building roof tops and roadways (NYCDHMH, 2008). On the potential for heat-related illnesses, NYCDHMH highlights children as having the greatest risk for succumbing to heat-stress and emphasizes that the key to prevention is avoiding overheating and dehydration.

More recently, the California Environmental Protection Agency's Office of Environmental Health Hazard Assessment (CalEPA OEHHA) conducted a multi-year study of the potential health effects associated with the use of crumb rubber containing turf fields and playground mats. Although no actual health effects were investigated, CalEPA found that many players and their parents expressed worries about the temperature of the crumb rubber-covered synthetic turf fields, with approximately 80% of participants reportedly feeling overheated on these fields (CalEPA, 2018).

Concluding Remarks on Synthetic Turf and Surface Temperature:
Individuals engaging in physical activity on synthetic turf surfaces are more likely to experience hotter local temperatures than they would with similar activities on natural grass turf. Prolonged exposure to high temperatures (and humidity) without proper rehydrating increases the risk of a myriad of heat-stress related medical conditions (e.g., heat exhaustion, heat stroke), and individuals exerting physical activity, particularly children, on synthetic turf on a hot sunny day are at higher risk of such effects. However, studies on the association between playing on synthetic fields and the incidence of exertional heat illnesses are inconclusive. This is likely due to the variability in types of synthetic turf fields and the range of influence that meteorological

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[2] USEPA Federal Research on Recycled Tire Crumb Used on Playing Fields https://www.epa.gov/chemical-research/federal-research-recycled-tire-crumb-used-playing-fields

factors play on the turf on any given day. In addition, health effects are usually caused by multiple complex exposure conditions, including heat, humidity, rehydration, as well as individual susceptibility, which may confound correlative studies. Similarly, studies demonstrating the impact of synthetic turf on the heat-island effect in urban environments are minimal, most-likely because any increased local heat from a synthetic turf field in an urban environment is negligible compared to that from the rest of the built environment. Nevertheless, it is important to consider that any individual in close proximity to synthetic turf on hot sunny days will experience hotter temperatures at least transiently. This is particularly true for urban communities, which already suffer from a lack of green spaces on which to recreate.

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