Artificial Turf and Natural Grass:

a comparative analysis of environmental impact, chemical exposure, injury, surface heat, playable hours and cost

PSEG Institute for Sustainability Studies Green Teams Project
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1. Executive Summary

Justification and Context

Centennial Field is a 13-year-old turf field located in the Township of Verona that is approaching the end of its useful life. This raises the issue of whether or not the new field should remain artificial turf or be converted back to a natural grass field. As we reach a tipping point in the current climate crisis, it is important across the globe to consider paths of environmental conscientiousness. However, the issue of artificial turf versus natural grass remains contentious across territorial lines. While natural grass has been a reliable playing surface for decades, artificial turf gained popularity for its claims of saving water and lower cost while enhancing the number of hours athletes could play on the field. Due to its struggles with environmental and human health impacts, research is needed to indicate whether widespread adoption is justified.

Main Takeaways

In the conversation on artificial turf versus natural grass, natural grass is recommended overall when examining environmental impact, chemical exposure, injury, surface heat, playability, and cost. Natural grass is found to be superior when prioritizing environmental impact, safety via chemical exposure, reduction of surface heat, and cost, however, natural grass has lower potential playable hours. While there were inconsistent results, injury rates were found to be mostly similar in both artificial turf and natural grass, with considerations for abrasions and foot injuries being higher in artificial turf.

Environmental Impact

Neither artificial turf nor natural grass fields are perfect for the environment. Artificial turf is better for water conservation and low maintenance but can cause issues with microplastic pollution and high greenhouse gas emissions. Natural grass fields better support the natural ecosystem and maintain runoff; however, they have high water usage and maintenance needs. Sustainable practices are needed for both field options, with natural grass needing proper grass selection and organic management and artificial turf needing less reliance on fossil fuels and an efficient and environmentally friendly end-of-life process.

Chemical Exposure

Natural grass is the safer option when considering chemical exposure risks. Artificial turf contains per-poly fluoroalkyl substances (PFAS), also known as forever chemicals, which are a major risk in artificial turf when it comes to human health and has been linked to varying cancers and other health effects. Metals and toxic substances such as lead are also a concern of artificial turf. While organic management of natural grass can also include toxic metals that impact human health, this does not compare to the risks associated with artificial turf. For either playing surface, looking into the different routes of exposure helps in the understanding of how people can better protect themselves.

Injury

Research results on injury rates between artificial turf and natural grass are somewhat inconsistent. There is some evidence to suggest that artificial turf’s higher traction could lead to higher rates of some lower extremity injury rates, and more frequent abrasions. A well-maintained surface is important for either type of field to keep injuries low.

Surface Heat

Artificial turf can reach significantly higher surface temperatures, up to 80 degrees Fahrenheit hotter than natural grass, which can cause significant harm and even death to adolescents and adults. This is especially concerning when understanding how high heat exposure can cause external heat illnesses. There are new artificial turf technologies that are advertised to mitigate these temperature differences, though they come with their own limitations.

Playability
Artificial turf can be played on for more hours annually than natural grass. That being said, Centennial Field will not require as many hours as artificial turf is advertised to handle because its main demographic is school-aged children playing sports that are not practiced year-round. Some case studies of well-maintained fields indicate that it may be possible for a natural grass field to withstand the number of playing hours currently scheduled, but there is no guarantee. If a natural surface is selected, proper construction and maintenance are crucial for its success.

Cost Benefit Analysis
Considering the costs of installation, maintenance, removal, and disposal of both artificial turf and natural grass, artificial turf has higher installation costs, while natural grass has higher maintenance costs. When looking at a 25-year period, natural grass has a lower overall cost since it does not require reinstallation.

Conclusions
Based on research, we found that overall, organically managed natural grass was the best option.

Recommendations
Based on our conclusion, we recommend using natural grass with the following considerations:

- Frequent maintenance to improve playing hours and reduce injury on natural grass
- Careful selection of chemical additives, including ensuring organic fertilizers do not contain as many synthetic substances.
- Careful construction, including water irrigation and drainage systems that are cyclical, if possible, to reduce water waste and consumption
- Selection of the best grass type for the specific climate to reduce the need for irrigation and reseeding
- The hiring of a full-time organic land management contractor to reduce costs while ensuring playability and field health

Our final recommendations include four policy options: two for natural grass, one for artificial turf, and one for hybrid turf. The recommendations are summarized in Table 7.1.

The main recommendation is natural grass policy option 1 which begins with constructing a field with a drainage and irrigation system to reduce water usage of the field. We also recommend seeding the field with Perennial ryegrass or Kentucky bluegrass due to its durability and ability to thrive in New Jersey's cool season climate. Kentucky bluegrass is favorable for field hockey usage, as it is an active sport on Centennial Field due to its ability to be trimmed below the specific sport height requirements. With either option of grass, it is recommended to use a sand-based root zone to aid in field health. We also highly recommend a full-time organic land manager to ensure the field is well maintained to reduce injury rates and increase playable hours.

While it is not our main recommendation, if artificial turf is selected, we recommend for artificial turf to be sourced locally to reduce emissions caused by travel. For the turf itself, we recommend using polyolefin or polyethylene to reduce the abrasiveness of the field. Another option can be nylon or polypropylene which are commonly used, however, have high environmental impacts due to water usage and emissions. For the infill, we recommend using a natural material such as cork or coconut to greatly reduce the human health and environmental impacts of the field. If this is not an option, we recommend using an infill made from thermoplastic elastomer due to its heat reduction capabilities. To reduce injury rates, we recommend frequent maintenance and testing infill replacement and hardness testing.

2. Introduction

What is Sustainability

Sustainability in this context is a systematic way of making services and products of high quality to meet peoples' needs and at the same time incorporating the economic, environmental, and social impacts. Sustainability was reflected in researching artificial turf and natural grass as well as final decision-making and all steps that lead to reaching our team goals.

Natural Grass Background

Natural grass fields are most commonly constructed with Kentucky bluegrass, perennial ryegrass, and tall fescue in cool season climates like New Jersey. (Advanced Turf Solutions, 2023). In warmer climates, bermudagrass is also popular. They are constructed after selection of e type of grass, soil mixture, and drainage system. Soil texture is crucial for field drainage; most fields use a soil mixture with native soil and additives such as sand or a completely new mixture if the native soil is unsuitable for sports (SportsTurf, 2018). Adding a drainage and irrigation system is essential for grass health and to reduce water usage which is a significant issue for natural grass fields. Drainage systems also decrease the time a field remains unplayable after a storm. . Maintenance of natural grass fields is important for field success. Common practices include mowing, overseeding, and watering. Other important practices include maintaining soil health by balancing soil pH and levels of nutrients such as potassium and phosphorus, aeration, and top dressing.

Artificial Turf Background

Artificial turf differs by name and structure across the globe. Setting roots in the 60s, artificial turf (synthetic turf, artificial grass, or plastic grass) has run through many changes with the current and most popular version being the third generation (Jastifer et al. 2019). Artificial turf is most commonly made up of synthetic grass fibers (polypropylene, polyethylene, and/ or nylon) and tire crumb infill from recycled tires. The construction base differs according to the site, however, every outdoor field needs to be made from porous components to ensure drainage (Jastifer et al. 2019). Some artificial turf fields will have a shock-absorbing pad above the base, above that will be the turf which has fibers attached to a backing that is added either through adhesive or tufting (Jastifer et al. 2019). Infill is used in the space between the artificial blades of grass and typically has rubber (Jastifer et al. 2019). Either through stitching or gluing, sections of artificial turf grass are then pieced together to form the turf field (Jastifer et al. 2019). While it has been stated that artificial turf requires no maintenance, in actuality, to be performance-ready, artificial turf goes through several daily or weekly maintenance procedures such as brooming, raking, infill refills, repatching whenever there are rips or tares, sweeping, dragging, loosening and redistribution of infill and cleaning (Jastifer et al. 2019). Artificial turf has both benefits and drawbacks which falls under water usage, pollution, runoff, life cycle, and emissions. Artificial turf can be problematic in terms of disposal because it is made of non-biodegradable materials and proper large-scale recycling has yet to be developed, therefore artificial turf is generally incinerated or dumped.

Hybrid Turf Background

A hybrid type of turf is made partly of natural and artificial fibers providing a medium between natural and artificial turf. In most hybrid systems, artificial fibers are sewn into natural turf, or an artificial grass carpet is placed over natural grass. Although hybrid turf is not extensively studied in this report, it presents an option that may balance the advantages of both types of surfaces.

Project Goals

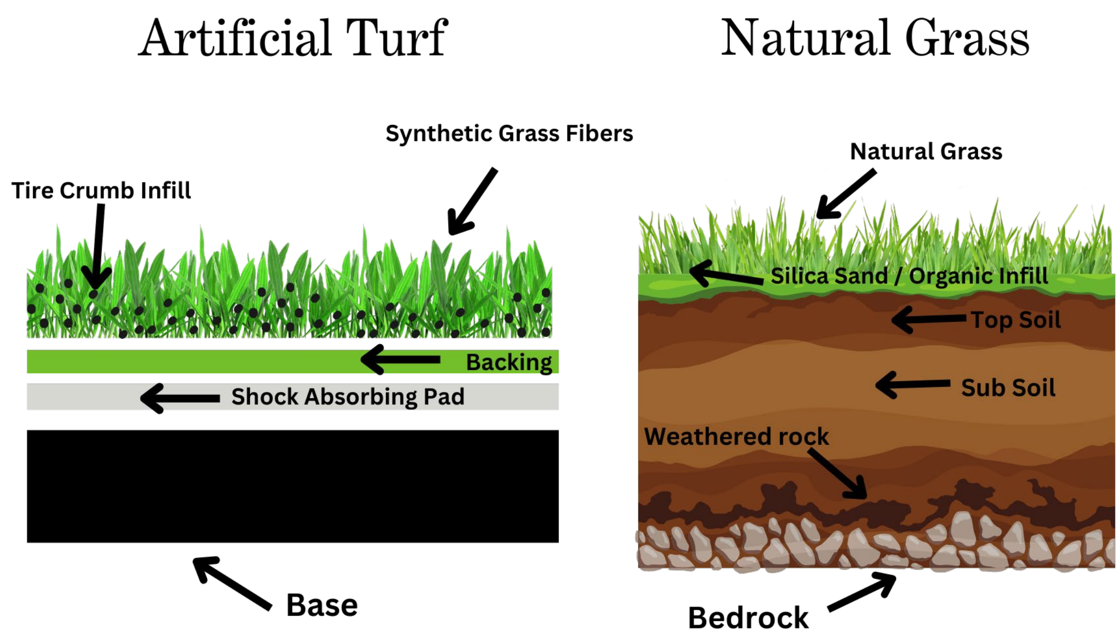
The Green Team serving the Township of Verona plans to present information on artificial turf and natural grass to the Verona town council and the public. As an organization focused on sustainable development, Green Teams aims to guide Verona toward a sustainable solution for Centennial Field. Recommendations will include:

- Costs for each option over a 25-year period
- An environmental impact assessment
- Information on playable hours and injury rates
- Information on chemical conditions and heat disparities
- A general proposal for the type of turf to install

Study Site: Township of Verona

The Township of Verona contains six municipal fields. Recently, the town declined to install artificial turf on Everett Field, a baseball field, raising concerns about the future of Centennial Field. Centennial Field is a 13-year-old artificial turf field that is reaching the end of its useful life and this brings concern to whether or not the new field should remain artificial turf or be converted back to a natural grass field. Verona faces increased pressure from various interest groups, making this a difficult decision. Further, it must consider new stormwater ordinances that would require additional stormwater mitigation if an artificial turf surface were to be installed.

Figure 1.1. *Structure of Artificial Turf and Natural Grass*



3. Deliverables

1) **An in-depth cost benefit analysis** based on synthesis of current literature and consultation of experts. Analysis should include longsited information on installation, options for maintenance, and when relevant, replacement. Report should also take into account the relevant stormwater

ordinance in Verona that classifies artificial turf as an impervious surface and would be relevant for a project of this size.

2) **An objective comparative environmental impact assessment** of artificial turf and natural grass. Assessment should consider all aspects of environmental consideration, including, but not limited to: water usage, energy consumption, emissions, and life cycle breakdowns. With examination of playing surfaces there is emphasis on manufacturing, maintenance and disposal requirements which are understood for options of each type of field to lessen overall environmental impacts. The assessment should consider the impact on the environment with emphasis on both artificial and natural grass field materials as well as additives necessary for maintenance and functional aspects of surfaces such as water retention and drainage.

3) **An assessment of current knowledge on playability** of artificial turf and natural grass. Assessment should consider factors impacting the number of playing hours possible on different playing surfaces if installed in Verona in the long term, including types of maintenance necessary. Assessment should include information on data on similar fields in the surrounding area and comparison to scheduled hours on fields in Verona.

4) **A review of current knowledge on injury risk to players** on artificial turf and natural grass fields. Review should include information on current research studies that directly compare playing surfaces and specific important injury categories.

5) **A review of chemical exposure risk to players** on artificial turf and natural grass. Report should consider material components of playing surfaces as well as additives required in different maintenance plans and the risks they pose to players in both the short and long term.

6) **A report on heat considerations** on artificial turf and natural grass. Report should consider current research on heat disparities between playing surfaces, risks involved in high heat levels, and potential mitigating factors for high levels of heat. Report should also include supplemental site heat specific data for Centennial Field and nearby turf and natural grass fields in different weather conditions to assess the current state of fields in Verona.

7) **A final proposal for turf type and infrastructure** a final cumulative report to be submitted to the town council, accompanying a presentation to the council and public.

4. Methodology

First, we familiarize ourselves with the study area: Centennial Field. This included site visits and meetings with local subject experts including Verona's public works director, recreation director, and an engineering firm. Then, we conducted background research on both playing surfaces which included watching webinars and reading academic journals and other relevant literature to gain a comprehensive view of artificial turf and natural grass.

4.1 Environmental Impact Assessment

We reviewed academic journals and peer reviewed articles examining various aspects of both artificial turf and natural grass.. These aspects inspected include life cycle, water usage, substrates, runoff, and pollution, which encompasses emissions, microplastics, and chemical leaching. The information and data collected was then used to create graphs and charts explaining the environmental impact of both artificial turf and natural grass fields.

4.2 Chemical Exposure
We conducted an extensive literature review on the chemical exposure and organized it into various sections. One section focused on the history and impact of major chemicals, particularly per- and polyfluoroalkyl substances (PFAS), known as "forever chemicals." Additionally, we examined the different types of fertilizers used on natural grass and reviewed research on their potential dangers. We also explored viable options for organic fertilizers, assessing their benefits and limitations compared to conventional chemical fertilizers. This comprehensive approach provided a deeper understanding of chemical exposures associated with both artificial turf and natural grass, guiding our recommendations for safer field management practices.

4.3 Injury
We reviewed relevant literature comparing rates of injuries on artificial turf and natural grass. Injury categories included are lower extremity injuries, concussions and head injuries, and abrasions. Other external factors such as maintenance, weather, and sex of participants are taken into account.

4.4 Surface Heat
In addition to reviewing relevant literature, we used Honest Observer by Onset (HOBO) temperature logger devices to measure the surface heat of an artificial turf and natural grass field in the Township of Verona. We utilized eight HOBO devices to collect temperature data in three different adjacent fields: Centennial Field–our primary focus as an artificial turf field; Liberty Field–a newer artificial turf field; and Veterans Field–a natural grass baseball field. The HOBO devices were connected to the mobile app and then placed at various locations on the fields to continuously collect data for our specified time frames. Infrared thermometers were also used to collect heat data at varying sections of the field. Our first data collection day occurred during a heat wave, however, we also collected temperature data on a sunny 90-degree Fahrenheit day and on cloudy days to observe the surface temperature variations. The data collected allowed us to generate charts and graphs to compare and analyze the heat conditions emitted from these three fields, which aided in the understanding of the potential health implications.

4.5 Playable Hours
Our investigation into playable involved reviewing claims from both artificial turf industry and natural grass experts on how many hours their products and fields could withstand annually. Supplemental data was also collected from neighboring towns and reports on organically managed natural grass fields. Over 20 small towns (populations around 20,000) were contacted to collect information on the number of hours that they are able to use their fields for. Two responses were received. Fields included are multi-use, similar to Centennial Field. Supplemental case studies on natural grass fields were also collected.

4.6 Cost Benefit Analysis
We met with experts from two innovative companies in the field of sports turf management. These consultations provided us with insights into the latest technologies, best practices, and industry standards. The experts shared their experiences and professional opinions on the cost-effectiveness of different types of turf, as well as the potential long-term benefits and drawbacks of each option. We also met with engineers and were provided installation and maintenance estimates for Centennial Field to use in our analysis.We also researched articles to provide data on the timeline of both installation and maintenance processes for artificial turf and natural grass fields. This included initial preparation, installation duration, and ongoing maintenance activities. Cost Comparison: By comparing the costs of installation and maintenance, we were able to identify the most cost-effective option over a 25 year period. This analysis took into account factors such as the frequency of maintenance activities, the expected lifespan of the turf.

We calculated the inflation rate of 2.5% by averaging the inflation rates over the past ten years. This was done by adding the annual inflation rates for each of the ten years and then dividing the total by ten.

5. Results

5.1 Environmental Impact

Section Summary

In a conversation on natural grass and artificial turf, it is crucial to examine environmental considerations and life cycle aspects– water usage and runoff, pollution, and energy consumption. Maintenance of recreational sports fields, artificial or natural, requires the use of water and energy to ensure playability and aesthetics. Mitigating the effects of pollution and green gas emissions on the planet is critical in environmental conscientiousness. Overall, water usage was found to be higher in natural grass fields, however, natural grass fields have lower pollution, runoff, and emission levels. This environmental impact assessment will highlight the important factors of both artificial turf and natural grass to make recommendations that pursue sustainability on all fronts.

Artificial Turf - Environmental Impact

Life Cycle (Manufacturing, Installation, Field Usage, Removal & Disposal)

Artificial turf is made using synthetic polymers based from fossil fuels, which is both energy and water intensive (Krüger et al. 2013). The synthetic grass at the top layer of artificial turf is created by using synthetic petroleum based polymers which are connected to a layer of textiles and latex with holes in it (Magnusson & Mácsik 2017) which can be made from polyurethane (PUR), latex rubber, polyethylene (PE), polypropylene (PP), polyethylene terephthalate, or polyamide (William et al. 2023). The most common type of infill, which is used to support the artificial grass fibers, is made from recycled end-of-life tires (ELT) (Magnusson & Mácsik 2017). This infill can also be made with thermoplastic (TPE), ethylene propylene diene monomer (EPDM), recycled EPDM rubber (R-EPDM), styrene-butadiene rubber (SBR), thermoplastics, sand, or from natural materials such as cork or coconut fiber (William et al. 2023). This infill can also be mixed in with small grain sand to aid in shock absorption followed by a shock pad under the artificial turf layer that is made with a porous elastic material (Magnusson & Mácsik 2017) that can be made with SBR and/or PUR (William et al. 2023). Under this can be a subbase of sand and crushed rock which is followed by a drainage system (Magnusson & Mácsik 2017) that can be made with PP and/or EPDM (William et al. 2023).

To make artificial turf, the process first starts with a synthetic polymer: polypropylene, polyethylene, or nylon, pellets which are mixed with dyes and chemical stabilizers and then formed into thin strands that resemble the shape of natural grass (Dunn, 2018). These synthetic blades are then tufted or stitched into a textile layer forming the top layer of the artificial turf (Dunn, 2018) which is then covered in a stabilizing material, such as latex, and cured with heat (Made How, 2015). After the artificial turf is cured, the blades are cut to the desired length, tested for durability and strength (Dunn, 2018), and finally packed to be shipped off (Made How, 2015). The transportation mode and process of the turf differ and should be considered when taking into account the environmental impact of artificial turf. Once brought to the field site, the installation process begins with the leveling of the concrete or soil, and then a drainage system is installed (Made How, 2015). Once the turf is laid down infill materials, such as tire crumb and sand, are spread across the field to maintain durability and ensure stability (Bø1 et al. 2023). During its lifetime, estimated average between 6-10 years, the artificial turf field will go under varying maintenance including sweeping, dragging, loosening, redistribution of infill, and cleaning (SportsTurf, 2018). The artificial turf will also require minor repairs such as replacing ripped sections of turf or seam repairs (SportsTurf, 2018). At the end of the life of artificial turf, there is research regarding the recyclability of the turf, however, due to the lack of proper recycling plants, artificial turf is often dumped in landfills or incinerated (Bø1 et al. 2023).

Water Usage

An advantageous factor of artificial turf is the amount of water needed to maintain the field. While water is not required for the irrigation of artificial turf, it can be used to cool off turf when it overheats (Cheng et al. 2014). Otherwise, water is not required to maintain the field which can save between 0.5-1 million gallons of water a year (Cheng et al. 2014). While water is saved during the lack of irrigation, water usage is high for artificial turf during the manufacturing process which increases the overall water usage for artificial turf (Bø1 et al. 2023). Plastic production is high in water usage at an average of 22 gallons per pound of plastic (Water, 2022), using this conversion, for the area of Centennial Field, it was found that Centennial Field used an estimated ~1.3-2 million gallons of water during the production of the artificial turf. If water is used to cool the artificial turf field, it would be an additional 250,000 gallons of water a year. With water for cooling and production added together and divided by the average lifespan of artificial turf, there would be an annual water usage of 390,000-450,000 gallons of water a year.

Runoff

Artificial turf is considered a semi-or fully impervious surface (Simpson & Francis, 2021). Artificial turf reduces infiltration due to reasons including synthetic grass catching the rainfall before it can reach the soil, low permeability rates of plastic grass, less pore space in the substrate due to a lack of grassroots, and the lack of a natural transpiration process. (Simpson & Francis, 2021). In a study comparing natural grass to short and long artificial turf, it was found that long artificial turf had the highest amounts of runoff which had rates comparable to asphalt road surfaces at 56% percent (Simpson & Francis, 2021). Artificial turf with short grass blades was found to have more efficient drainage systems which allows for rainfall to pass through to the ground (Simpson & Francis, 2021). Artificial turf was found to have more runoff levels than natural grass, with long artificial turf having higher amounts of runoff than short artificial turf (Simpson & Francis, 2021). When artificial turf and natural grass were tested, results found plastic thatches and grass fibers in the runoff (Simpson & Francis, 2021). Long artificial turf has higher runoff amounts than shorter artificial turf with both types of artificial turf having higher levels of runoff than natural grass (Simpson & Francis, 2021). Natural grass is better at retaining water and delaying drainage whereas short artificial grass drains the fastest (Simpson & Francis, 2021). Since there is minimal to no inorganic nitrate absorption by artificial turf, it was found to have high levels of nitrate runoff (Chang et al. 2022). When nitrate is introduced in excess to the environment it can cause harmful impacts such as eutrophication and health impacts. Plastic grass fibers were found in the simulated runoff which emphasized the issue of plastic pollution from artificial turf (Simpson & Francis, 2021).

Pollution / Emissions

Microplastics

Microplastic is when plastic is broken down to less than 5 mm in length. Artificial turf contributes significantly to plastic pollution and ends up in rivers and ocean waters through water runoff (William et al. 2023). In a study conducted in Spain, collecting water samples from the sea surface, fibers from artificial turf were found in half of all samples, with higher concentrations on the sea surface than in rivers (William et al. 2023). The study done on the west and southern coasts of Spain highlights that the fibers of artificial turf which range from meso to macro size can make up 15% of plastic debris in aquatic environments such as rivers and the sea (William et al. 2023). Rainfall increases the dispersal of artificial turf to drainage water systems or water streams which all end up in rivers or oceans (William et al. 2023). Fibers of artificial turf were at their highest concentrations during the rainy season of the area (William et al. 2023), which is a cause for concern due to the predicted changes in weather patterns globally. With the potential health and environmental risks associated with microplastics, the European Union passed a ban on microplastics which included artificial turf crumb rubber infill (Zuccaro et al. 2024). Crumb rubber infill is often made with shreds of end-of-life tires and includes chemical contaminants such as polycyclic aromatic hydrocarbons (PAHs), heavy metals, per- and polyfluoroalkyl substances (PFAS), and more which cause damage to humans and nature (Zuccaro et al. 2024). Microplastics are a cause for concern due to their inability to biodegrade which means they can persist in the environment for centuries as forms of pollution and hazard (Zuccaro et al. 2024).

Emissions

From a life cycle analysis on Recycled tires (RT), Virgin thermoplastic elastomers (TPE), Virgin ethylene propylene diene monomer (EPDM), Recycled EPDM (R-EPDM) from cables and automotive mats, it was found that the highest energy use and greenhouse gasses emissions for infills were observed in TPE, followed by EPDM (Magnusson & Mácsik 2017). With heavy metals, there is a concern about leachability with Zinc being found in detectable amounts in RT and high concentrations in R-EPDM (Magnusson & Mácsik 2017). There was a minimal to high risk associated with infill and turf fibers due to dermal, ingestion, and inhalation exposure (Magnusson & Mácsik 2017). Due to the use of nonrenewable petroleum-based products, there are high emissions– specifically CO2 during the manufacturing, production, transportation, installation, maintenance, and end-of-life processes (FIFA, 2017). Of a 9000m2 artificial turf field with a life expectancy of 10 years, it is estimated that the t/CO2 is 55.6, which is three times that of a natural grass field (Cheng et al., 2014). It is predicted that the greenhouse gas emissions from an artificial turf field will double when the components of the field are not recycled at the end of its life (Cheng et al., 2014). Since there are no proper recycling facilities for artificial turf, it is normally incinerated or dumped.

Maintenance

Maintenance of artificial turf fields can cause harmful environmental impacts in terms of pollution and emissions. During maintenance of artificial turf, it is recommended that the field is cleaned for hygiene and health (SportsTurf, 2018) which can include cleaning solvents and cleansers (IdealTurf, 2023) which can contain harmful chemicals that cause pollution. Cleaning solutions, depending on its chemical makeup, can lead to differing levels of impact on the surrounding environment. It is also recommended that the infill of the turf is replenished to help reduce injury (SportsTurf, 2018) due to the high emissions and chemicals in infill, replenishing these levels for safety would further increase the emissions and pollution power of artificial turf. For artificial turf fields that are meant for multiple sports, differing color markings are recommended via dyed turf or paint which should also be accounted for when considering a thorough outlook on the environmental impact of artificial turf (SportsTurf, 2018).

Pollution

When considering the pollution power of artificial turf, air pollution needs to be understood to gain a full understanding of the environmental considerations of artificial turf. Air pollution can be caused by the dust of rubber granules, PAHs, and volatile organic compounds (VOCs), but the amount found with artificial turf still falls under regulation limits (Bø1 et al. 2023). Compared to SBR and TPE, EPDM produces the most airborne pollutants (Bø1 et al. 2023). The PAHs of outdoor sports facilities are lower than indoor ones, however, it was found that both do not present large risks to the local city (Bø1 et al. 2023).

Natural Grass - Environmental Impact

Natural Grass sports fields have existed for many decades at this point, but during the mid to late 1900s sports fields began switching to artificial turf fields which changed the game in sports (Weeks, 2015). In modern day, natural grass sports fields struggle to keep up with artificial turf fields in many environmental aspects including with water and energy usage. Natural grass can reduce surface temperatures, biodegrade airborne pollutants, support insect and small animal life, and act as a carbon sink (Cheng et al., 2014).

Life Cycle

One of the first steps a community should take in the installation of a natural grass field is soil testing (Green Building Alliance, 2022). This gives a comprehensive study of which grasses would be best for the field as well as the types of soil additions or enhancements that can be used to create a durable and healthy field (Green Building Alliance, 2022). With this, comes the need for the right crown and shape which can greatly impact drainage and the fields longevity and efficacy in the long run (SportsTurf, 2018). It is crucial to find the right growing medium for the grass taking into account location and climate which will impact water, nutrients, and drainage capacity (SportsTurf, 2018). There are varying grass species for differing protective capabilities, drought resistance, root system, and weed resistance which can all dictate the longevity and playability of the field (Green Building Alliance, 2022). The type of turfgrass chosen will also affect the types of maintenance that is required for a playable field (SportsTurf, 2018). For example, if irrigation is not a viable option for an area, it is important to choose a variety of grass that has high drought resistance or if the area has very extreme winters and summers, it is important to consider grass varieties that are less sensitive to climate extremes (SportsTurf, 2018). A subsurface drainage system may be installed to better drainage efforts and decrease excess saturation of the natural grass (Kowaleski et al. 2015). After the natural grass field is either seeded or installed, maintenance will be required to preserve a playable environment. Aeration is highly recommended to enable air, water, and nutrient penetration and decrease irrigation needs (Green Building Alliance, 2022). Depending on the operations of the field, natural grass fields can be enhanced with fertilizers, pesticides, and herbicides and reseeding / overseeding, and topdressing (Massey et al. 2004). Regular maintenance of the natural grass field such as watering, mowing, fertilizing, and reseeding is often required for dependable natural grass fields (Cheng et al., 2014).

Water Usage

Water usage of natural grass is one of the biggest downfalls when in comparison to an artificial turf field. Irrigation of natural grass fields is extremely water intensive (Cheng et al., 2014) with natural grass fields being the largest irrigated area in the United States at an estimated 163,800 km2 (Chang et al. 2022). A natural grass sports field in the United States can average 0.5 to 1 million gallons of water usage a year (Cheng et al., 2014) which is an extreme cost to water conservation efforts.

Runoff

In urban areas, environmental impacts caused by replacing natural grass with artificial turf is exacerbated leading to an increase of rainfall runoff and decreased infiltration which can lead to issues such as flooding and increased local waterway pollution (Simpson & Francis, 2021). Urban drainage is considered sustainable when water goes through a surface and is able to be held within the surface or infiltrated by vegetation before being brought back into the atmosphere using evapotranspiration (Simpson & Francis, 2021). Natural grass fields help reduce soil erosion and urban heat island effects along with controlling flood (Simpson & Francis, 2021). In a study comparing natural grass to short and long artificial turf, natural grass was found to be more effective at slowly releasing infiltrated water and also storing the water (Simpson & Francis, 2021). These aspects of natural grass aid in decreasing the prevalence of flash floods and overall decrease the risk of floods compared to artificial turf (Simpson & Francis, 2021). However, during times of high rainfall, natural grass fields can often become flooded or waterlogged which can cause damage to the field, increase runoff, and decrease playing time (Cheng et al., 2014). This can be reduced and remediated by well maintained natural grass fields or those with drainage systems.

Pollution / Emissions

Pesticides can cover a vast variety of compounds such as herbicides, insecticides, and more and are mainly used to protect vegetation from insects and reduce unwanted plant growth (Aktar et al., 2009). Pesticides pollute and negatively impact water, soil, and the surrounding environment including harming animal and non-targeted plant life (Aktar et al., 2009). Several comprehensive studies done by the U.S. Geological Survey found that one or more pesticides are found in over 90 percent of water and fish samples and often in concentrations that were harmful to aquatic life (Aktar et al., 2009). Pesticides are also dangerously prevalent in groundwater in over 43 states, which can take many years and dollars to clean up if at all possible (Aktar et al., 2009). When pesticides are sprayed, they can travel up to several hundred miles, harming human health and polluting the air along the way (Aktar et al., 2009). It is important to note that the Township of Verona does not currently use pesticides.

Microorganisms are crucial in a healthy soil and environment. When natural grass fields are treated with pesticides, populations of microorganisms are killed off leading to soil degradation (Aktar et al., 2009). The use of painting for the lines on the field can be another environmental impact consideration. Furthermore, emissions on a natural grass field are much lower than that of an artificial turf field because it is a natural carbon sink, the majority of a natural grass fields' emissions are due to maintenance and construction of the field.

Organic Pesticides / Fertilizers

Organic fertilizers can be defined as "naturally occurring mineral sources that undergo minimal human intervention, mainly through physical extraction" (Panday et al. 2024). Organic fertilizers are unpredictable in their effectiveness in terms of nutrient release time which decreases their dependability (Panday et al. 2024). Organic fertilizers can be organized into six categories: animal-based, plant-based, mineral-based, specialty organic fertilizers, microbial inoculants, and wastewater-derived organic fertilizers, with plant-based and microbial inoculants having the lowest environmental impact (Panday et al. 2024).

Limitations

Some limitations for this environmental impact assessment include time and research constraints. With the allotted time of 8 weeks for research, there were some aspects of the report that were not able to be addressed in depth, such as the impact of paint on both artificial turf and natural grass, the use of machinery in maintenance of both, and best practices for all included factors. Another limitation is data consistency. Fields across the globe have different construction builds, soil types, climate patterns, etc. therefore, there remains a struggle to define approximate numbers in relation to water usage, emissions, and pollution power across the board. Finally, while research was done in a comprehensive and objective manner, it is impossible to understand all biases that may play a part in the websites, journals, articles, etc. that were referenced in this report.

5.2 Chemical Exposure

Section Summary

Studies have shown that the chemical exposure risk is much greater in an artificial turf field than a natural grass field. The use of artificial turf and tire crumb infill in sports fields and playgrounds has raised significant health and environmental concerns due to the presence of hazardous chemicals and metals such as per- and polyfluoroalkyl substances (PFAS).

PFAS are known to be persistent in the environment and can accumulate in human and animal tissues, leading to potential adverse health effects including developmental issues,immune system dysfunction,liver damage and increased risk of certain cancers. The application of organic and inorganic fertilizers on natural grass also warrants scrutiny due to the potential for nutrient runoff, which can lead to water pollution and negative impacts on aquatic ecosystems.The general public may not full know of the dangers posed by these chemicals, much like the lack of awareness regarding the risks associated with artificial turf. This lack of awareness can result in insufficient protective measures, further intensifying health and environmental risks.

History of PFAS

PFAS, which is found in artificial turf, has been widely used since the 1940s for its properties such as oil and water resistance. PFAS has been known within industry circles to pose significant health risks by as early as 1970 (Gaber et al., 2023). Studies conducted internally showed that PFAS compounds: Perfluorooctanoic acid (PFOA) and Perfluorooctane sulfonic acid (PFOS), were highly toxic if inhaled and moderately toxic if ingested. This information was kept hidden from the public for decades (Gaber et al., 2023).

Throughout this period, companies engaged in practices aimed at suppressing unfavorable research findings and shaping public perception to downplay concerns about PFAS toxicity (Gaber et al., 2023). Legal disclosures and investigative reports have since uncovered these tactics, revealing a deliberate strategy to delay regulatory scrutiny and hinder scientific research into the health impacts of these chemicals (Gaber et al., 2023). By the time the public health community began to uncover the true extent of PFAS toxicity in the late 1990s and early 2000s, substantial evidence had already accumulated within industry archives (Gaber et al., 2023).

The delay in the disclosure of this information had serious consequences for public health. It allowed widespread environmental contamination and human exposure to PFAS to continue unabated, potentially leading to adverse health outcomes such as liver damage, developmental disorders, and increased cancer risks (Gaber et al., 2023).

Cancer Risk Associated with PFAS Exposure

While the concealment of health information regarding PFAS chemicals by industries has been one of the many displays of corporate negligence and ethical misconduct, a lot of research is being done to understand the effects of PFAS and how best to go about addressing its widespread presence, especially on artificial turf which has gained popularity over the years. Efforts are also being made to find ways to mitigate the damage caused by PFAS and educate people on the associated risks.

The potential cancer risk associated with artificial turf has been a subject of considerable research and debate. Marsili et al (2017) evaluated the hazard indices and cumulative excess risk values for cancer from chemicals in crumb rubber, concluding that these were below levels of concern (Bleyer, 2017). However, they noted that polycyclic aromatic amines in crumb rubber could potentially increase cancer risk with long-term, frequent exposure under very hot conditions (60°C/140°F). Some studies have implicated polycyclic aromatic amines as occupational lymphomagens. An occupational lymphomagen is a substance or factor that is found in the workplace and is capable of causing a lymphoma, which is a type of cancer that occurs in the lymphatic system. However, recent systematic review and meta-analysis of cohort studies have refuted this association (Bleyer, 2017).

Cancers such as lymphoma, brain cancer, testis cancer, leukemia, and sarcoma occurred at expected rates without the need to consider external factors (Bleyer, 2017). Moreover, comprehensive studies by the Washington State Department of Health and the Dutch National Institute for Public Health and the

Environment found no link between artificial turf and an increased incidence of cancer in susceptible age groups. Additionally, polycyclic aromatic hydrocarbons (PAHs), which are widespread environmental pollutants that are formed in the combustion process of carbonaceous materials at high temperature, were tested. This means that burning or extremely high temperatures of PFAS produces PAHs. Even though PAHs are extremely dangerous, no significant differences in PAHs metabolites in urine were observed between users of synthetic turf fields and those using grass fields (Bleyer, 2017).

Other Health Effects from PFAS Exposure

PFAS have been linked to various adverse health effects, including lower birth weight, increased serum cholesterol levels, and reduced antibody response to vaccinations (Oddný Ragnarsdóttir et al., 2022). These chemicals, while not metabolized in humans, can be biotransformed from precursor compounds like 8:2 FTOH and PFOSA into PFOA and PFOS, increasing human exposure (Oddný Ragnarsdóttir et al., 2022). This biotransformation can alter gene expression, potentially heightening cancer risk.

The liver's role in PFAS reabsorption has prompted studies on their impact on liver function, revealing further health implications (Oddný Ragnarsdóttir et al., 2022). For instance, the C8 study of a highly exposed US population found high PFOA levels associated with increased risks of functional thyroid disease, kidney cancer, and testicular cancer. Similarly, a birth cohort study in eastern Massachusetts found that PFNA and PFOS levels in early pregnancy plasma were inversely associated with birth weight and linked to a higher risk of preterm delivery (Oddný Ragnarsdóttir et al., 2022). Additionally, research on the Danish National Birth Cohort demonstrated a consistent negative association between PFOS and PFOA levels and birth weight, alongside a nearly two-fold increase in the risk of preterm birth (Oddný Ragnarsdóttir et al., 2022). These findings indicate the serious health hazards posed by PFAS exposure from artificial turf, necessitating urgent attention and mitigation efforts.

Toxic Chemicals in Artificial Turf / Chemical Leaching

Synthetic grass fibers have been found to contain high levels of lead, prompting legal actions and the replacement of fields in California, as well as commitments from manufacturers to eliminate lead from their products (Massey, 2020). Studies conducted by institutions such as the Massachusetts Toxics Use Reduction Institute (TURI)'s chemical hazard-based comparison of synthetic turf materials highlights the findings of similar assessments by the Norwegian Environmental Agency and the National Institute for Public Health and the Environment (RIVM). Tire crumb infill, commonly used in artificial turf, contains polycyclic aromatic hydrocarbons (PAHs), which is a highly carcinogenic compound, and is less regulated than consumer products or toys (Massey, 2020). High-aromatic oils used in tire manufacturing are significant sources of PAHs, which contribute to the total daily intake of these carcinogenic compounds. The levels of PAHs in tire crumb samples were quantified and several previously unreported PAHs were identified (Massey, 2020). Tires, composed of materials like styrene butadiene rubber, accumulate various chemicals over their lifecycle, including lead, zinc, arsenic, and cadmium. Studies have shown that artificial turf has a high potential to leach toxic metals such as copper, zinc, cadmium, barium, manganese, and lead (Massey, 2020).

Assessment of Natural Grass Management Practices

The Township of Verona has restrictions for fertilizer use on their natural grass fields (Township of Verona Municipal Code §451). This means that it becomes crucial to look into the safety of organic options, if a natural grass option was found viable for Centennial Field.

Understanding organic land management requires familiarity with some key terms. A soil amendment is any material mixed into the soil to improve its properties. In contrast, mulch is a material placed on the soil surface and is not considered a soil amendment. Fertilizer refers to a product that contains at least one essential plant nutrient. Organic fertilizers, derived from natural sources, also contain essential plant nutrients. The nutrients in organic fertilizers are often in forms that plants cannot immediately use. Soil microorganisms need to convert these nutrients into bioavailable forms before plants can absorb them.

This process results in a slower release of nutrients compared to inorganic fertilizers. Additionally, organic fertilizers improve soil properties by adding organic matter.

When using soil amendments, it is important to consider two key factors: release time and application method. First, release time refers to the period during which nutrients from organic products become available for plant uptake (*Organic Fertilizers*, n.d.). Organic products require the activity of soil microorganisms to release nutrients. This activity depends on soil temperatures above 50ºF and adequate soil moisture (*Organic Fertilizers*, n.d.). In dry or cold conditions, nutrient release from organic sources is delayed. Knowing the release time helps in scheduling the application of these products effectively (*Organic Fertilizers*, n.d.). Second is the application method which one can go about in different ways. Some products are tilled into the soil with machines or hand tools, while others are applied as sprays, mixed with a surfactant, and sprayed in a fine mist on the leaf surface when temperatures are below 80ºF (*Organic Fertilizers*, n.d.). A surfactant is simply a surface -active agent that reduces the surface tension of a liquid. Additionally, some products can be injected into drip or overhead irrigation systems, a process known as fertigation (*Organic Fertilizers*, n.d.).

Before applying any fertilizer, it is important to conduct a soil test to determine what deficiencies your soil might have (*Organic Fertilizers*, n.d.).Two examples of fertilizers include alfalfa meal or pellets and corn gluten meal. Alfalfa meal or pellets, often used as animal feed, are primarily used to increase organic matter in the soil (*Organic Fertilizers*, n.d.). They also offer nutrients and a high availability of trace minerals. These contain triacontanol, a natural fatty-acid growth stimulant, which promotes quick growth of grass (*Organic Fertilizers*, n.d.). This makes alfalfa meal or pellets an excellent fertilizer option for field resting periods, as the grass can grow back healthy and strong.

Corn gluten meal is another fertilizer option with a high percentage of nitrogen. Products containing corn gluten meal typically carry a warning to allow one to four months for decomposition in the soil before seeding (*Organic Fertilizers*, n.d.). Corn gluten meal is also marketed as a pre-emergent weed control for annual grasses in bluegrass lawns (*Organic Fertilizers*, n.d.). This is particularly beneficial for fields with Kentucky bluegrass, one of the recommended grass options for Centennial field due to its suitability for cooler climates.

Organic fertilizers, derived from plant or animal products, offer numerous benefits for soil health and plant growth by enhancing soil structure, water retention, and nutrient availability (Yasuo Mitsui Nakamaru et al., 2023). They contribute to a healthy growing environment by slowly releasing nutrients, thus reducing the danger of over-fertilization and requiring fewer applications (Yasuo Mitsui Nakamaru et al., 2023). However, they can also pose environmental risks due to the potential presence of pathogenic microorganisms, pesticide residues, and heavy metals. Selecting high-quality organic fertilizers is crucial to minimize these risks. In contrast, inorganic fertilizers provide rapid nutrition directly to plants but do not improve soil health. They often result in nutrient runoff, polluting local waterways, and can damage beneficial soil microorganisms due to their salt content, ultimately impairing the soil's ability to retain water and air. While inorganic fertilizers are cheaper in the short term, their long-term effects are less beneficial compared to organic fertilizers (Yasuo Mitsui Nakamaru et al., 2023). The latter not only add natural nutrients and feed important microbes in the soil but also continue to enhance soil composition and texture over time. Despite the higher initial cost, the long-term benefits of organic fertilizers make them a sustainable choice for promoting healthy plant growth and maintaining soil fertility.

Limitations

There are limited data for some of the important parameters needed to estimate exposures for athletes using synthetic turf fields with tire crumb rubber infill. The lack of this data leads to applications of assumed values or values applied from nonequivalent scenarios, both of which can lead to considerable uncertainties in exposure estimates.In some cases, conservative parameter values have been applied in order to inform conservative and protective assessments, but that could lead to exposure overestimation.Conservative parameter values involve using higher exposure levels or lower safety margins to account for uncertainties, aiming to protect public health and the environment even if the actual risk may be lower.There are a large number of chemical substances associated with tire crumb rubber infill that have not been included in most exposure assessments (Gong et al., 2019). Lack of certainty in the identification of many of these chemicals and lack of quantitative measurements inhibits a more complete cumulative exposure assessment (Gong et al., 2019). When reviewing literature on natural grass one challenge is the fact that Soil composition varies widely, influencing how fertilizers interact which complicates efforts to generalize chemical exposure risks. Moreover, temporal variability, which is the effects of fertilizers that can change over time due to degradation or transformation processes in the soil, poses a challenge (Yasuo Mitsui Nakamaru et al., 2023).This temporal shift makes it hard to fully capture the long-term implications of fertilizer use in short-term study periods (Yasuo Mitsui Nakamaru et al., 2023).

5.3 Injury

Section Summary
Studies tend to find no significant conclusive difference in overall injury rates in major categories, such as lower extremity injuries and head injuries. Within that, artificial turf tends to have higher injury rates in some common categories of injuries, such as ankle and foot injuries, especially in professional football, and higher abrasions. Many complicating factors keep this conclusion from being cut and dry, including many studies having small sample sizes, differences in injury rates due to weather, type of sport, sex of participants, and, importantly, maintenance of surfaces.

Background
Researchers have been investigating the difference in injury rates between artificial turf and natural grass since 1992, when John Powell published an article linking artificial turf surfaces to increased incidence of knee injuries in professional football (Powell & Schootman, 1992). Other researchers at the time published results similarly linking artificial turf to increased injury rates. Second and third-generation artificial fields made significant changes to their designs, including adding a shock pad and infill, significantly softening the playing surfaces and decreasing injuries (O' Leary et al., 2020). Studies on injury rates are complicated by a number of factors, including the size of the study, sex of participants, type of sport, level of play, weather, and maintenance of the playing surfaces. For instance, studies have found injury rates to be 1.8 times higher on unacceptably hard fields (Twomey et al., 2012). Few research articles attempted to measure injury rates in their entirety, so analysis in this report has focused on comparing three major categories of injuries: lower extremity injuries, (ankle, knee, foot, ect.) concussions, and abrasions.

Lower Extremity Injuries
Large meta-analyses of cohort studies and studies examining injury data over many seasons, especially in professional and elite-level sports, most often find no significant difference in overall lower extremity injury rates between artificial turf and natural grass (Bjørneboe et al., 2010; Ekstrand et al., 2011; Gould et al., 2023; Soligard et al., 2012; Williams et al., 2011). That being said, few studies find higher rates of injury on natural grass, and the ones that do are often funded by industry itself (Gould et al., 2023). Higher rates of ankle and foot injuries have also more consistently been found on artificial turf than natural grass (Gould et al., 2023).

Overall injury rates don't take into account stratification by sports. In other words, some sports see more of one type of injury on one surface, while other sports see no difference or more of that injury on another surface. It is well documented, for instance, that knee injuries are more common on artificial turf than natural grass in collegiate and professional football (Balazs et al., 2015; Dragoo et al., 2013; Hershman et al., 2012; Williams et al., 2011). One study examining aggregated National Collegiate Athletics Association (NCAA) data over ten years for football even found that in competitions, athletes experienced posterior cruciate ligament (PCL) injuries at 2.94 times the rate on artificial turf than natural grass (Loughran et al., 2019).

That being said, NCAA soccer data over the same period found no difference in match injuries. They also found a 8.67 times higher anterior cruciate ligament (ACL) injury rate on natural grass during training (Howard et al., 2020). Studies focusing on soccer teams often find no difference in overall lower extremity injury rates (Calloway et al., 2019; Ekstrand & Nigg, 1989), with some also finding lower injury rates on artificial turf (Williams et al., 2013), and others finding higher rates of ACL injuries for women, but not for men on artificial turf (Xiao et al., 2022).

Explanation for Higher Ankle and Foot Injuries

Synthetic turf lacks the ability to divot and release a player's foot under high pressure, thus putting more pressure on the player's lower limbs (Jastifer et al., 2018). Biomechanical studies also suggest that peak pressure experienced by players is higher in some circumstances on artificial turf than on natural grass (Sultan et al., 2021). Both patterns could explain higher ankle and foot injuries on artificial turf.

Concussions

Diagnosis of concussions in sports has been increasing in recent years, with some estimating up to 3.8 million sports-related traumatic brain injuries annually in the United States alone (Langlois et al., 2006). Likely, this increase in diagnosis is not entirely due to an increase in injuries but also an increase in public awareness around the issue, changes in diagnosis, the creation of rigorous head injury assessments and a better understanding of concussions among physicians (O' Leary et al., 2020; Baldwin et al. 2018). Changes such as these lead to inconsistencies in the literature. For example, reported incidences of concussions due to head-to-surface interactions on artificial turf range from less than 6% to as high as 30% (Meyers et al 2019, Clark et al 2017, O' Leary et al., 2020).

Female athletes may be more susceptible to concussions (Covassin et al., 2003), more concussions occur when it is colder (Smoliga et al., 2023), more concussions occur later in the season (Smoliga et al., 2023) and that more concussions occur on poorly maintained surfaces, including those with low infill weight (Meyers, 2019). Multiple studies have found that concussions occur more frequently on natural grass than on artificial turf (O'Leary et al., 2020; Meyers, 2004; Ranson et al., 2018). However, this finding is not universal. A study looking at data from the 2012 to the 2019 NFL regular seasons found that, on average the risk of concussion on natural grass was 0.78 times lower compared to artificial turf (Smoliga et al., 2023) and a study with data from 24 universities over 3 seasons found no difference in concussion risk between field turf and natural grass (Meyers, 2010), as did an analysis of NFL data from 2012-2013 . Data on severity of concussions from different surfaces is similarly inconsistent (Meyers, 2010; Heinzelmann et al., 2023).

Abrasions

Any playing surface can scrape up an athlete's arms, legs, or face if they slide across it. Abrasions, which can also be considered scrapes or "turf burns," are generally minor injuries. They do not usually cause an athlete to miss time on the field, which is likely why fewer studies focus on comparing abrasions between artificial turf and natural grass and why they are likely underreported (Twomey et al., 2014). Importantly, abrasions can be a concern when they cover a large area and when foreign objects become embedded (Peppelman et al., 2013). Additionally, any injury that opens the skin increases the risk of infection.

Even though fewer scholarly research articles include and examine abrasions, the ones that exist overwhelmingly support the idea that artificial turf is more abrasive than natural grass and has been since its inception. Even products marketed as non abrasive, while found to, in fact, be less abrasive than their other artificial turf counterparts, were found to have higher rates of abrasions and other skin injuries than natural grass fields (Meyers et al. 2004). This finding is consistent with those of Williams et al., (2016), which compared the rate of abrasions between artificial turf and natural grass in rugby and the majority of studies cited in the meta-analysis, Fuller et al. (2007), that compared skin injuries between playing surfaces. It is no wonder why Williams et al. (2016) also found that players reported skin abrasions as being the biggest drawback of artificial turf. Another study by Fuller et al. (2007), found that football players were more hesitant to try sliding tackle moves, with defenders and midfielders showing the greatest negative perceptions, likely because those positions have to tackle most often. Importantly, at least one study, which asked participants to slide on wet and dry artificial turf and natural grass, found no difference in the severity of abrasions between the surfaces (Peppelman et al., 2013)

Explanation for Abrasion Rates

Artificial turf could produce more abrasions than natural grass for a couple of reasons. The first and most obvious is that the components of artificial turf are inherently more abrasive than those of natural grass. Plastic, infill, and sand are inherently better for opening skin than blades of grass and soil (or, in some cases, sand). It has also been suggested that the higher surface heat of artificial turf increases the likelihood of abrasions and burns (Everything Sports Organisations Need to Know, 2023).

Figure 5.3.1: *Summary Chart of Injury Research*

	ARTIFICIAL TURF	NATURAL GRASS
Overall Lower Extremity Injuries	=	=
Knee	=	=
Hip	=	=
Foot and Ankle	↑	
Concussions	?	?
Abrasions	↑	

Limitations

Time was the main constraint on researching this section. There are hundreds of relevant articles comparing injuries on artificial turf and natural grass, many of them with contradictory results. At the same time, for some categories such as abrasions, there may not be enough data to come to firm conclusions. There was not enough time to conduct detailed literary analysis on every injury that could be sustained in every sport. The categories that were chosen were those that are talked about most often and have more research attached to them. Because of the history of artificial turf having higher injury rates in some categories, it is possible studies are more likely to focus on those injuries, and not areas where natural grass may fare worse.

5.4 Surface Heat

Section Summary

Existing studies and supplemental site specific data find artificial turf to be significantly hotter than natural grass. The rising incidence of exertional heat illnesses (EHI) among high school athletes in the U.S. underscores the critical need for enhanced heat safety measures in sports environments. The increased vulnerability of adolescent athletes to EHI, due to physiological differences and a lack of comprehensive understanding among coaches and parents, highlights the importance of accurate and localized temperature monitoring. The discrepancy between meteorological data and on-site conditions, particularly on artificial turf fields that can reach dangerously high temperatures, exacerbates the risk. This evidence suggests a pressing need for adopting more precise measures, such as the wet-bulb globe temperature, and implementing strict guidelines for athletic activities in hot weather. While various mitigation strategies, including surface irrigation and specialized products, show promise in reducing surface temperatures on artificial turf, they are not without limitations and often come with significant costs.

Background

Exertional heat illnesses (EHI) are on the rise across highschool athletes in the U.S. In the 5-year block from 2005 to 2009, more EHI deaths occurred in organized sports than in any other 5-year period over the past 35 years (Kerr et al., 2013). Heat related illnesses can range from milder symptoms such as heat cramps and heat exhaustion to very dangerous pathologies such as dehydration and heat stroke (Lugar-Amador et al, 2004). Adolescent athletes are at a higher risk of these illnesses due to the physiological differences compared to adults (Falk & Dotan, 2008), and the limited understanding coaches, parents, players, ect., have in determining the safety of the fields. Many organizations rely on heat advisories issued by services such as the National Weather service. The prevalence of EHIs are determined by many factors, not just surface temperature. Environmental parameters such as wind velocity, humidity, air temperature and radiant temperature all affect the capacity for humans to dissipate heat (Cramer et al, 2016). The National Athletic Trainers Association and American College of Sports and Medicine have recommended using a wet-bulb globe temperature to measure the safety of fields. An observational study was conducted comparing meteorological data with surface data taken using various athletic surfaces including artificial turf and natural grass. The main findings were that the National Weather Service wet-bulb globe temperature misreported the on-site temperature measurements by about 0.67°C (1.2°F) (Pryor et al. 2017). Due to the difficulty of measuring and reporting accurate and relevant temperature readings, many organizations follow strict guidelines when deciding to cancel or postpone sporting events. New York City Parks and Montgomery County Public Schools in Maryland developed the following heat guidelines for artificial turf fields: anytime the outdoor temperature exceeds 80 degrees fahrenheit, coaches exercise caution in conducting activities on artificial turf fields; when outdoor temperatures exceed 90 degrees fahrenheit, coaches may hold one regular morning or evening practice (before noon or after 5pm); when the heat index is between 91–104 degrees fahrenheit between the hours of noon and 5pm, school athletic activities are restricted on artificial turf fields to one hour, with water breaks every 20 minutes. In Verona, the parks and recreation department goes by the Rutgers Youth Sports Council’s recommendations. All recreation coaches are required to hold a Rutgers SAFETY council certification. They follow guidelines located in the Appendix under Table 9.3.3 and Figure 9.3.4, in order to gauge the level of outdoor activity and when to close the fields for excessive heat. Unlike other counties, these regulations do not differentiate between playing surfaces.

Heat Disparities of Artificial Turf and Natural Grass

It is well-documented in the literature that artificial turf fields have significantly higher surface temperatures when compared to natural grass fields. According to one study the artificial turf's surface temperature was 37°F higher than asphalt and 86.5°F hotter than natural grass (Williams & Pulley, 2002). They recommended that Brigham Young University set a safe temperature limit of 50°C (122°F) as just 10 minutes of skin exposure to an artificial turf field at this temperature could result in injury. One study had division 1 collegiate football athletes practice in Tempe, Arizona in July 2019 (Wardenaar et al, 2023). The participants trained on artificial turf outside on the first day and trained on natural grass outside the second. On each day certain physiological parameters were measured including: core temperature, skin temperature, heart rate, and sweat rate (calculated using other parameters). The distinct microclimates were measured and compared using air temperature, relative humidity, vapor pressure, and the incoming/outgoing wave radiation. Although the solar radiation was less on the day of the outside artificial turf trial, the surface temperature recorded was 67°C (140°F) vs. 33°C (91°F) for natural grass. Physiological measurements showed similar core and skin temperatures and self-reported levels of heat stress when not exercising. However, during exercise, skin temperature was significantly higher on the artificial turf, compared to natural grass. This trend was also observed in core temperature, rate of perceived exertion (RPE), and self-reported heat stress. This is one of the few recent studies that was able to observe not only differences between the microclimate, but also the effect on the athletes during exertion. The Center for Sports Surface Research at Penn State University conducted studies comparing the surface and air temperatures of synthetic turfs made from different fiber and infill colors and materials. They found that during hot, sunny conditions, the maximum surface temperatures averaged between 140°F and 170°F on artificial turf surfaces (McNitt & Petrunak, n.d.). Surface temperature differences of the components of artificial turf were observed with the black mat (shock pad) reaching the highest temperatures about 10°C (18°F) higher than the turf and infill which maintained similar temperatures (Falk & Dotan, 2008).

Some of the reasons suggested for the heat disparity between artificial turf and natural grass are the higher spectral reflectance of artificial turf, natural grass is made up mostly of water, and more of the heat at the surface of a natural grass playing surface is transferred into the layers underneath (Falk & Dotan, 2008). Spectral reflectance is a measure of how much energy a surface reflects at a specific wavelength, also known as albedo. The low albedo of the turf, along with the lower specific heat capacity of the turf fibers and infill material, means that less energy is needed to heat the surface (Singh et al, 2024). Natural grass blades are made up of about 70% moisture, these plants undergo transpiration where liquid water within them evaporates and releases vapor and heat.

Mitigating High Surface Temperature of Artificial Turf

Surface irrigation has been shown to lower the temperatures of artificial fields, however, the cooling effect only seems to last about 20 minutes (McNitt et al. 2008). The reason irrigation of synthetic turf fields does not work, or at least have a lasting effect, is because the infill material used in these is often hydrophobic (McNitt & Petrunak, n.d.).

Some specialized products have also been found to reduce temperatures. Synthetic grass surfaces with ThermoPlastic Elastomer infill, Cool climate turf fibers, HydroChill and surfaces without a shock pad, are cooler than surfaces with styrene-butadiene rubber (tire crumb) infill or surfaces with a shock pad (Singh et al, 2024). Unfortunately, while these products reduce surface temperature, they may increase temperature in otherways. Cool climate turf fibers are designed to reflect more of the sunlight, reducing surface temperature, however, these may cause an increase in the radiant temperature above the surface. HydroChill when added to a synthetic turf surface increases moisture storage within the infill reducing surface temperatures, however, this may increase humidity above the surface (Singh et al, 2024). TCool, a cool climate turf fiber, is advertised as reducing the temperature of standard artificial turf fields by 35°F to 50°F. The company that produces this product is currently undergoing a lawsuit for $3.7 million dollars for fraud, negligence, and a breach of contract as the fields do not keep cool as promised (Jurado 2023). Many of these products are new, have not been sufficiently studied and tend to be much more expensive than typical artificial turf products.

Infrared Thermometer

Data was collected using infrared thermometers on three different days throughout the summer in Verona, NJ. On the first day two readings were taken from Centennial Field, the artificial turf field up for renewal, and Veterans field, a natural grass field in poor condition. On the second day two measurements were taken from the same fields, as well as Liberty field, a newer artificial turf field. The third day only one reading was taken at each of the same three fields. The ambient temperature at the time of collection was also recorded. All measurements were taken within a time frame of 20 minutes due to the proximity of the fields. Pictures were taken of the infrared thermometer reading and the area of the field where the measurements were taken, they can be found here in the Appendix under Table 9.3.1, Table 9.3.2 and Table 9.3.3.

Figure 5.4.1: *Recorded temperatures using an infrared thermometer of three fields in Verona, NJ across three days and the ambient temperature at the time*

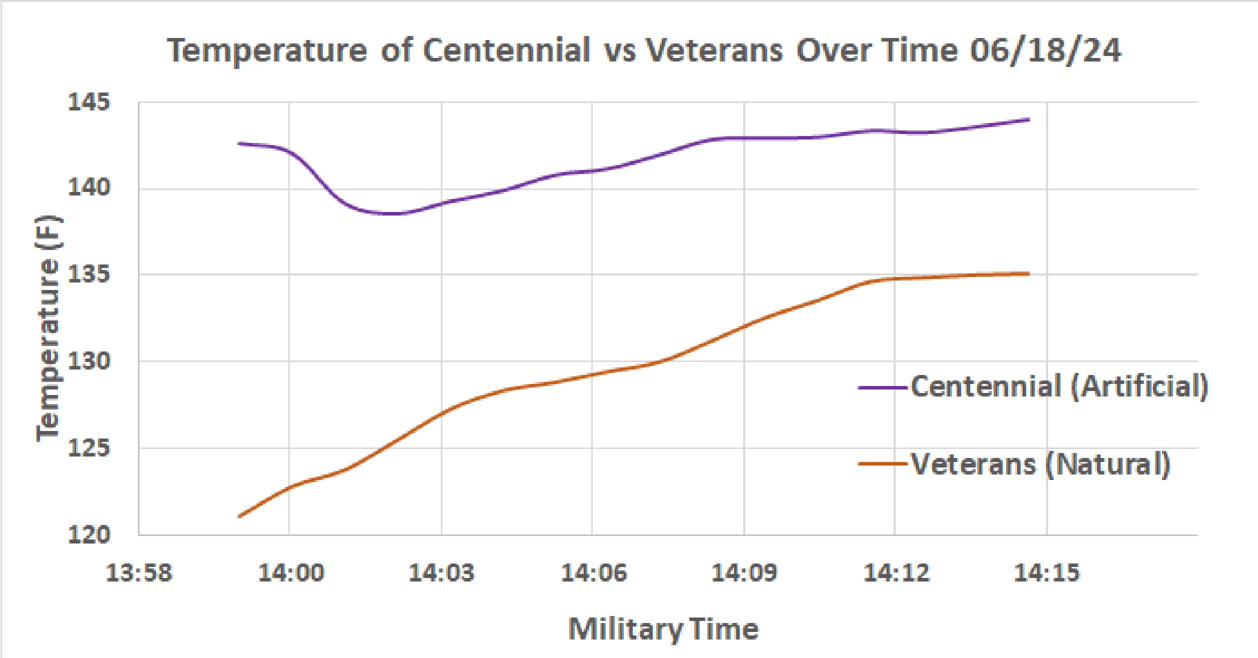
	Centennial	Veterans	Liberty	Ambient
	18-Jun-24			
Temperature (°F)	150.1	136.2	-	91
	151.7	108.3	-	91
	24-Jun-24			
	124.9	93.6	109.9	74
	133.2	92.8	120.4	74
	17-Jul-24			
	138.0	117.1	138.0	92

Based on the two readings of the first day, Centennial Field (artificial turf) was 28.7°F hotter than Veterans (natural grass). Both fields had higher surface temperatures compared to the ambient temperature of 91°F. The second day Centennial Field had the highest temperature with an average of 129.1°F, followed by Liberty Field, the newer artificial turf field, with an average temperature of 115.2°F, with Veterans' average temperature as the coolest of just 93.2°F. Once again all fields had higher temperatures than the ambient temperature of 74°F. The last day of data collection, Centennial and Liberty had equal temperature readings of 138.0°F, with Veterans measuring 117.1°F. The artificial turf fields in the case were 46°F higher than the ambient temperature of 92°F, while the natural grass field was only 25.1°F higher than the ambient temperature.

HOBO Data Logging

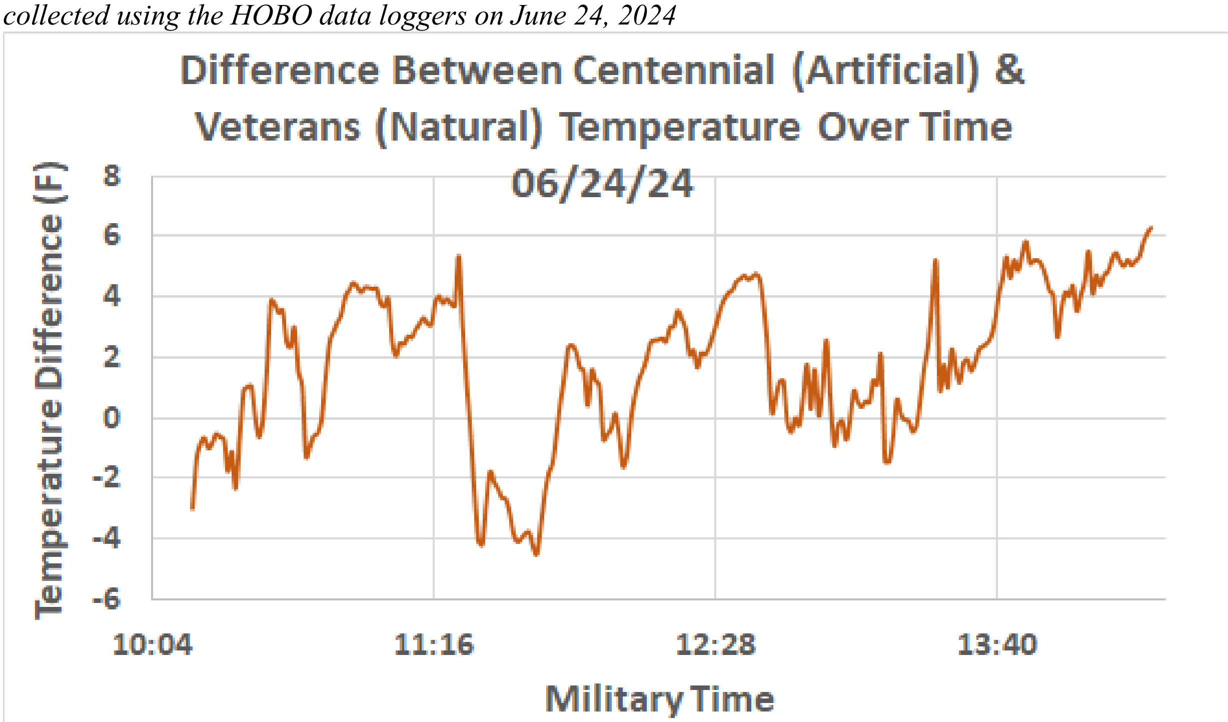
As mentioned in the methods section, Honest Observer By Onset (HOBO) data logging devices were used to collect surface heat readings The Figure 5.4.2 compares the surface heat temperatures of two fields in Verona, NJ over a 15 minute period. The data was logged from every minute from 2:00pm to 2:15pm on June 18, 2024. The atmospheric temperature recorded at this time was 91°F with a humidity of 61%, sunny, and wind speed of about 2.5 mph.

Figure 5.4.2: *Recorded temperatures using HOBO data loggers of Centennial Field and Veterans Field over time in Verona, NJ on June 18, 2024*



The average temperature of Veterans field throughout this time period was 129.6°F, while the average temperature of Centennial field throughout this time period was 141.7°F with a difference of 12.1°F. Figure 5.4.3 demonstrates the difference between the average of surface heat data collected throughout a 4 hour period of two fields in Verona, NJ. The data was logged every minute from 10:00am to 2:20pm on June 24, 2024. The atmospheric temperature recorded at the time was between 72°F and 79°F with a humidity between 52% and 43%, partially sunny, and wind speed between 3.5 and 5.5 mph.

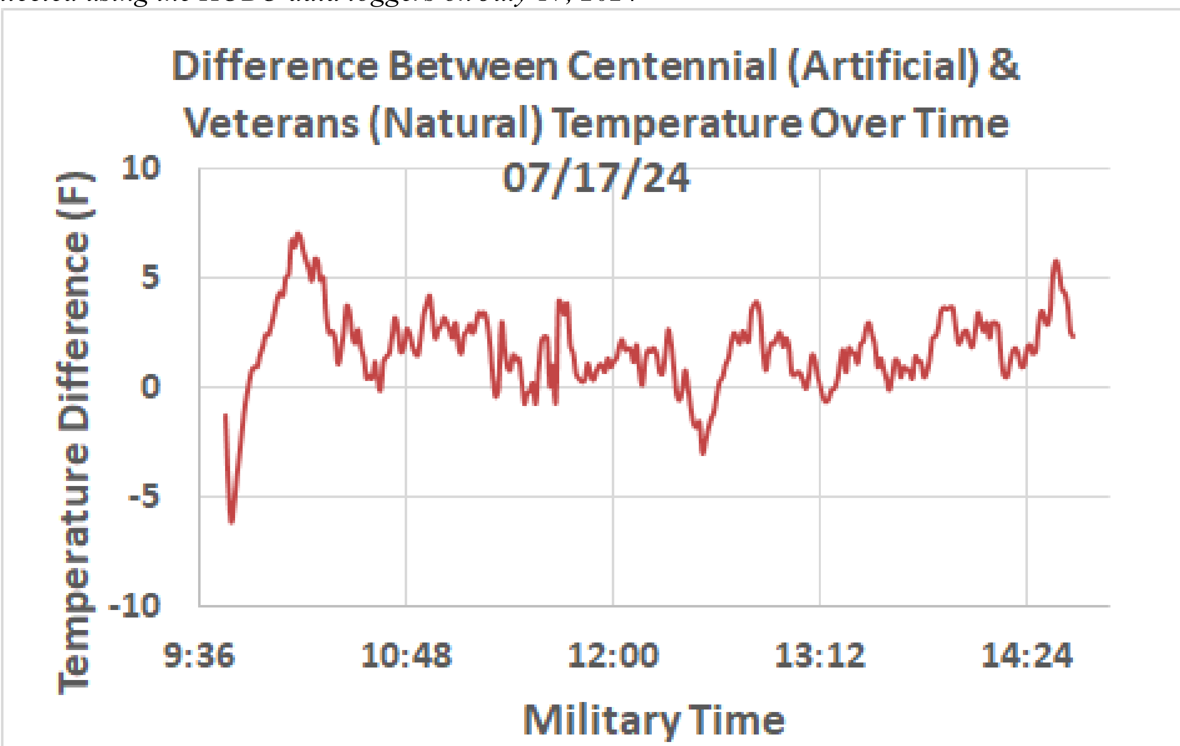
Figure 5.4.3: *Difference between Centennial Field and Veterans Field over time in Verona, NJ, from data collected using the HOBO data loggers on June 24, 2024*



When the temperature difference is positive and above x-axis, the surface temperature of Centennial Field is larger than the surface temperature of Veterans Field. The absolute value of the temperature difference did not reach much over 6°F for this day. There were sections of time where Veterans had higher surface temperature, however, most of the day Centennial was hotter.

Figure 5.4.4 shows the difference between the average of surface heat data collected throughout a 4 hour period of two fields in Verona, NJ. The data was logged every minute from 9:45am to 2:40pm on July 17, 2024. The atmospheric temperature recorded at the time was between 72°F and 92°F with a humidity between 50% and 44%, sunny, and wind speed between 9 mph and 12 mph.

Figure 5.4.4: *Difference between Centennial Field and Veterans Field over time in Verona, NJ, from data collected using the HOBO data loggers on July 17, 2024*



When the temperature difference is positive and above x-axis, the surface temperature of Centennial Field is higher than the surface temperature of Veterans Field. The absolute value of the temperature difference did not reach much over 5°F for this day and mostly stayed within a few degrees. However, Centennial still had higher temperature readings than Veterans for the majority of the day.

Limitations

Much of the research available on temperature differences between artificial turf and natural grass is heavily focused on surface temperature. This strategy does not paint the entire picture. Human heat exchange is affected by many factors and surface heat is just one small part of the puzzle. It was difficult to find up to date peer reviewed research on this topic that provided data for the full spectrum of environmental parameters. Further research needs to be done on how these differences between artificial turf and natural grass have a direct impact on human health. Additionally, more studies on the specific mechanisms that lead to such large heat disparities between artificial turf and natural grass need to be done.

There were large differences between values obtained on surface temperature using the infrared thermometer and the HOBO data loggers. The first day that data loggers were used, values obtained were very similar to the infrared readings. The second and third day that data was collected there were large differences between the two methods of collection. Possible sources of error could be attributed to the different climates on days of data collection, HOBO data loggers being more sensitive to ambient temperature rather than surface temperature, and/or user error. More data should have been collected using both methods to gain a better understanding of these differences, however, due to the time constraints for the project no further recordings were obtained.

5.5 Playable Hours

Section Summary

Although artificial turf can be used for more hours without visible damage, it decreases in quality until it needs to be replaced. Case studies of nearby towns show instances where natural grass can be used more than Centennial Field's current usage levels, but natural grass is used on average for fewer hours. See Figure 5.5.1 for a summary of the data. Natural grass fields vary in how many hours they can be used, and good construction and maintenance are crucial to their success.

Playable Hours on Artificial Turf

The turf industry consistently claims that their fields, when well maintained, can withstand an average of 3,000[1] hours of usage per year compared to 600-800 hours on a natural grass field (Artificial Turf or Natural Grass, n.d.; Construction, 2019; *Synthetic Turf Council*, n.d.). Research has yet to be conducted to verify this claim. However, owners of artificial turf fields generally agree that turf fields can be played on for long periods of time without rips or other visible damage. Based on a conversation with Verona's recreation director, Centennial Field has reportedly had to repair rips only a handful of times over its 13-year lifespan.

Wear on artificial turf fields is progressive, not cyclical, as with natural grass. In other words, wear on artificial turf fields builds up over time. The blades of artificial turf are made of plastic, which photodegrades. This means that over time, as the artificial turf field sits out in the sun, ultraviolet (UV) rays weaken the plastic and break it down (Protect Your Artificial Grass, 2024). Some artificial turf products are meant to slow UV degradation, but they do not claim to entirely prevent it (Synthetic Turf Field Durability - Astroturf, n.d.). The older a field is, the more sun it has been exposed to and the weaker the plastic blades are, allowing them to be trampled down, to break off, and to wear down otherwise. The more the field is used annually, the faster the field will decline in quality (*Protect Your Artificial Grass*, 2024). Plastic also becomes more brittle when cold, allowing it to break off more easily, which is why Verona's artificial turf fields are closed at temperatures below 39 degrees Fahrenheit, according to Verona's Public Works Director.

Playable Hours on Natural Grass

[1] Several manufacturers were contacted and asked to verify this statistic. As of the writing of this report, no response has been received. Likely, it is an estimate based on the assumption that artificial turf can withstand round-the-clock play and would be played on for almost the entirety of the year over 8 hours a day. FieldTurf, for instance, included a chart comparing its hours to those of natural grass, where it claimed that it would be used 48 weeks per year, 42 hours per week, as compared to 40 weeks per year, 20 hours per week, for natural grass (*Artificial Turf or Natural Grass*, n.d.).

Natural grass management experts generally do not make sweeping claims about the number of playing hours possible on natural grass because each case is different (ANC3G, 2024). The number of playable hours possible on natural grass varies based on the region's weather patterns, type of grass, type of substrate (what the grass is growing in, such as native soils or sand), amount and type of maintenance, field drainage system, what kind of sports will be played on the field, and the age of users, among other factors (Aldahir & McElroy, 2014; ANC3G, 2024). Only one source gave a tentative estimate of how the number of hours played on a field affected quality. Note that the source-based estimates are on Bermuda grass, a warm-season grass not used in New Jersey.

Table 5.5.1: *Expected field condition based on Hours of field use per year*

Field use (Hours per year)	**Expected field condition**
200 hours or less	Sustained good field conditions
400 to 600 hours	Good field conditions with some thinning of the turf and localized wear areas
800 to 1,000 hours	Fair field conditions; expect significant thinning and wear.
More than 1,000 hours	Significant turf loss, field surface damage, increased potential for athlete injury

Wear on natural grass relates to the amount of heavy traffic on each part of the field. Heavy play in any one area can compact the soil, inhibiting the amount of air and nutrients that can reach the roots of the grass, causing some of it to die. Heavy play on wet grass will also cause problems for the field and players. Grass on wet fields can come up in clumps, damaging the field and potentially injuring players. How quickly natural grass wears out and recuperates is different for every field.

Some consistent factors affect field quality and, thus, the number of quality playing hours possible:

1) Construction and maintenance for adequate drainage: It is difficult to overstate the importance of adequate drainage for a field. Compacted fields will not drain well, allowing water to sit on the surface longer and extending the time a field is unplayable after rain. Soils with some amount of sand, fields with grading, and fields with vertical slit or subsurface drainage systems drain faster (*Maximizing the Durability of Athletic Fields | Nc State Extension Publications*, n.d.; Murphy, 2005). Consistent aeration is also crucial to alleviating compacted soils[2].
2) Grass type: It is important that fields are constructed with durable grass that fits the local climate and usage patterns. New Jersey Climate favors cool season grasses, specifically Kentucky bluegrass, perennial ryegrass, and tall fescue. Seeding with these grasses is also important maintenance to fill in gaps in field cover (*Maximizing the Durability of Athletic Fields | NC State Extension Publications*, n.d*;* Murphy, 2005).
3) Maintaining soil health: For grass to grow vigorously and replenish after heavy use, it must grow in healthy soil. Testing and treating soil to maintain levels of nutrients such as Phosphorus and

[2] Aeration is a process that utilizes a machine to make slits or holes in the soil to allow air and other nutrients to penetrate to deeper root systems. It should be done multiple times a year, especially in heavily used sections of a field, for proper maintenance.

Potassium, balancing pH levels, and utilizing soil amendments such as peat moss and compost are crucial to high-performance grass (Murphy, 2005).

4) Other maintenance: Mowing, watering, and fertilizing are necessary to help grass grow strong root systems, survive through drought periods, push out weeds, and generally grow well (Murphy, 2005). Practice on the field should rotate high-use drill areas when possible. (*Maximizing the Durability of Athletic Fields | NC State Extension Publications*, n.d)

As with artificial turf, there is no standard metric for what condition makes a natural grass field playable or not playable, which makes estimating playable hours on natural grass fields even more difficult. Often, it comes down to a judgment call or a school/municipality's specific policy. Take rain, for example; some towns have a policy for canceling games and practices when there is standing water on the field; others cancel when there is heavy rain for a day or more, and still, others cancel due to wet conditions generally (*Case Study: Marblehead, MA*, 2019; *Case Study: Martha's Vineyard, MA*, 2020; *Case Study: Springfield Mass*, 2019).

Case Studies for New Jersey Towns

Mahwah Township and the Village of Ridgewood provided us with data on the number of hours that they use their fields. Mahwah has two artificial turf fields that they use for an average of 1100 hours a year; they use their artificial turf fields more than their natural grass fields, which they use for an average of 640 hours per field per year. The Village of Ridgewood has many fields, all of which they use highly. They have one artificial turf field, which they use for 1500 hours, somewhat more than they use their natural grass fields, which they use for an average of 1292 hours annually. The Village of Ridgewood struggles somewhat with the quality of its natural grass fields and suggests that they may be using their fields for more hours than they can handle.

Case Studies for Natural Grass

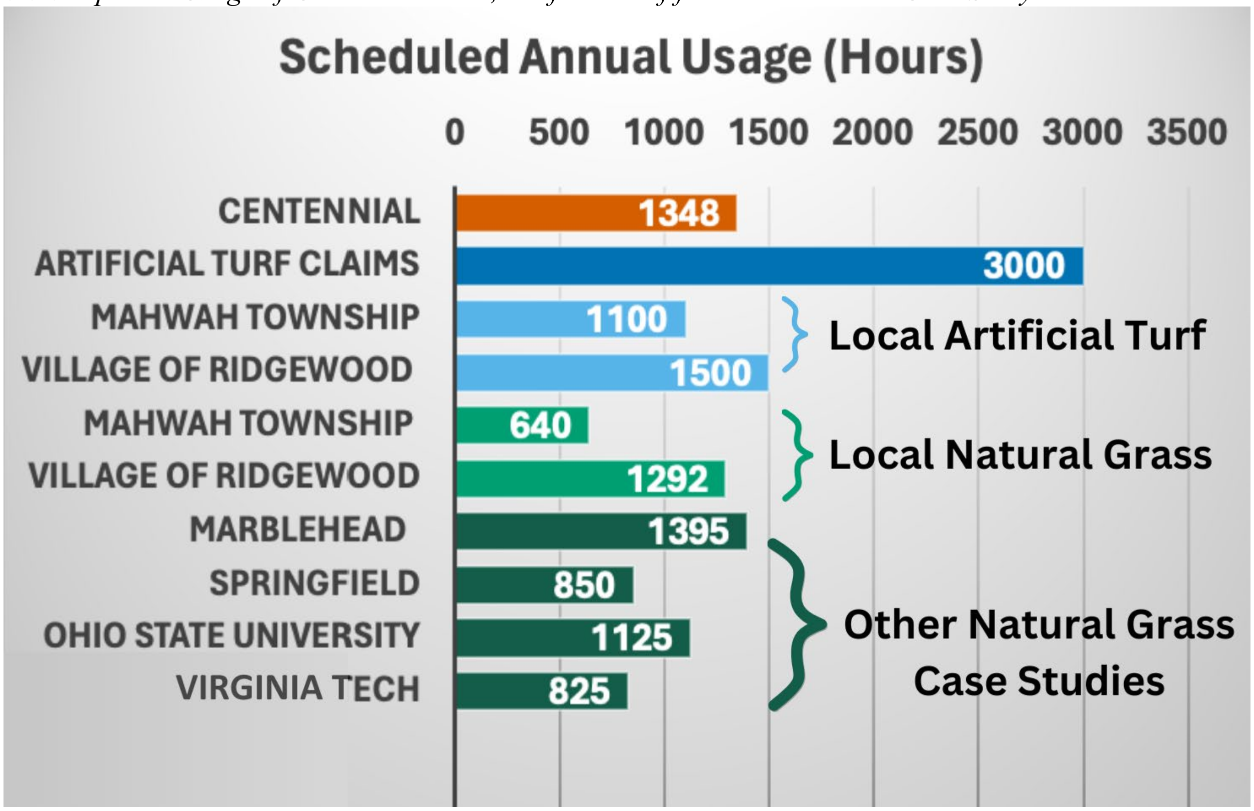
Some experts that presented in the Washington D.C. community meeting hosted on May 30, 2024, who manage high-stress natural grass fields claim that their fields are and can be heavily used, ranging from an estimate from the Soccerplex in Maryland of 40-50 hours weekly in peak months to a turfgrass Specialist at Ohio State University claiming that they get 25-50 hours a week without resting their fields, and lastly, an expert at Virginia Tech University claiming that their fields can withstand 25-30 hours a week (ANC3G, 2024). If used at these rates every week of the year, these experts would claim use of their fields between 1,300 and 2,600 hours a year. Sports generally do not practice all year so they likely have fewer hours of actual use on their fields.

Case studies on organically managed similarly sized sports fields also indicate that it is likely possible to get more quality playable hours out of natural grass fields when well maintained than the turf industry estimates. For instance, Marblehead Massachusetts' Hopkins field, which is 65,000 square feet and hosts scheduled soccer, lacrosse, football, and middle school physical education, is utilized for 1,680 hours of practice and gameplay annually. With informal use, it is estimated to be used for 1,860 hours in total (*Case Study: Marblehead, MA*, 2019).

Similarly, the Village School Lower Field in Marblehead, which is 65,340 square feet, is used for 1090 scheduled hours of youth soccer, boys lacrosse, and high school soccer annually, with additional hours scheduled for middle school recess and summer medical sports clinic, bringing the total scheduled use up to 2030 hours and total estimated use to 2210 (*Case Study: Marblehead, MA*, 2019).

That being said, Springfield, Massachusetts' Treetop Park has also been included, and it's 117,771 square foot playing space is only estimated to be scheduled for 850 hours a year, for it is only scheduled for use a few weeks a year, at 60 hours a week (*Case Study: Springfield Mass*, 2019).

Figure 5.5.1: *Reported Usage of Centennial Field, Artificial Turf field Potential and Case Study Fields*



Rainouts

Besides the scheduled hours a field can be used without rest during sports seasons, the next largest consideration for playability is how quickly a field can recover after a rainstorm. According to Verona's Public Works Director and Recreation Director, Verona's artificial turf fields recover faster after heavy rain than its natural grass fields, leading to games being moved from natural grass fields to artificial turf fields on occasion. Verona's natural grass fields are maintained by mowing and overseeding but not by aeration or other types of management, likely leading to higher compaction than would be otherwise. One of the above case studies, Marblehead, who closes their fields when there is standing water, closed their field only 5 times in total over the study period of 2018, and Springfield their fields a total of 12 times, both aerate at least 4 times a year. Neither have a drainage system, which would increase drainage speed.

Limitations

There is very little data available on playable hours for natural grass. Additionally, hours collected are scheduled hours, not possible hours. Fields included may be able to use their field more than is currently scheduled. Fields also may be overused, decreasing their quality. As mentioned, there is no consistent metric for what field condition makes a field playable, and both natural grass and artificial turf fields may lose field quality when played on for higher hours, but an estimation of that quality loss is not included in this report. The limited time in this project did not allow for a complete survey of nearby municipalities and their scheduled use and maintenance routines.

5.6 Cost Benefit Analysis

Section Summary

Based on our research, we found that in the long run artificial turf is more expensive than natural grass. This difference is true even when a professional organic land manager's cost is considered. The main reason is the high cost of reinstallation every ten years necessary for artificial turf and the added cost of a stormwater management system. To determine the cost-benefit analysis of artificial turf and natural grass fields, it involves the evaluation of various types of fields and measurements. We conducted extensive background research to find maintenance, installation, disposal costs, etc. Research papers, case studies, and articles helped establish initial installation costs, maintenance costs, disposal costs, removal, etc. Experts in the turf industry, engineers, and professionals with finance backgrounds provided helpful information and feedback for the cost-benefit analysis. Aspects that they provided insight into included planning, looking at the long-term horizon of costs and the required infrastructure involved in these projects. In-depth help and advice were provided by data analysis and data presentation efforts by Analise Dyer, a Green Teams alum, who helped with the interpretation and presentation of the data. With help from all of these sources, we were able to look at the big picture needed to make a recommendation on the type of field for Verona. We are proposing three recommendations to the Verona Town Council: two for natural grass and one for artificial turf.

Cost Summary

Table 5.6.1: *Cost Analysis Summary of Centennial Field, Artificial Turf Field, and Natural Grass*

Centennial Field	Artificial Turf	Natural Grass (Rec. 1)	Natural Grass (Rec. 2)
Installation Total	$ 1,114,608	$ 975,401	$ 848,054
Annual Maintenance Total	$ 23,270	$ 59,000	$ 18,483
2025 Total Cost	$ 1,137,878.00	$ 1,034,401	$ 866,537.40
2050 Cumulative Cost (see Figure 5.6.1)	$ 4,568,608.68	$ 3,100,091.57	$ 3,749,828.41

Above is the cost summary for artificial turf, natural grass recommendation 1 which includes the cost of an organic land manager, and natural grass recommendation 2, which would have Verona manage their own field. For installation, artificial turf is more expensive; for annual maintenance, maintaining natural grass with the help of a professional manager is the most expensive. For the total estimated replacement and maintenance cost in 2025, artificial turf and natural grass recommendation 1 are cut very close, but artificial turf turns out to be the more expensive option. Finally, artificial turf becomes the most expensive option for the total estimated cumulative cost of 2050. See Figure 5.6.1 below for a graphical representation of cost over time.

The difference between the two natural grass recommendations are three big factors, construction, type/material, and maintenance. Natural Grass recommendation one we will implement a system to recycle water and will be using Kentucky bluegrass/ Perennial ryegrass sand-based root zone and seeding. Unlike the natural grass recommendation, 2 won't include recycling water and will use tall fescue, native soil, and sodding. Maintenance for recommendation one consists of frequency aeration 3-5 times a year, and full-time organic land management, unlike the second natural grass recommendation which needs short-term training for natural grass management, organic pesticides, and organic considerations in general. For more information on our final proposals outlined here, see section 7.2.

Financing costs were not factored into our report, as the installation costs across our recommendations are comparable. We focused on providing an accurate and comprehensive analysis of the direct installation expenses, finding that each option presented is within a similar range. By doing so, we aimed to offer a clear and fair comparison of the different seeding and turf options, allowing for an informed decision-making process without the influence of additional financing considerations. Our goal was to highlight the relative cost-effectiveness and benefits of each choice based on their inherent qualities providing a straightforward assessment for our stakeholders.

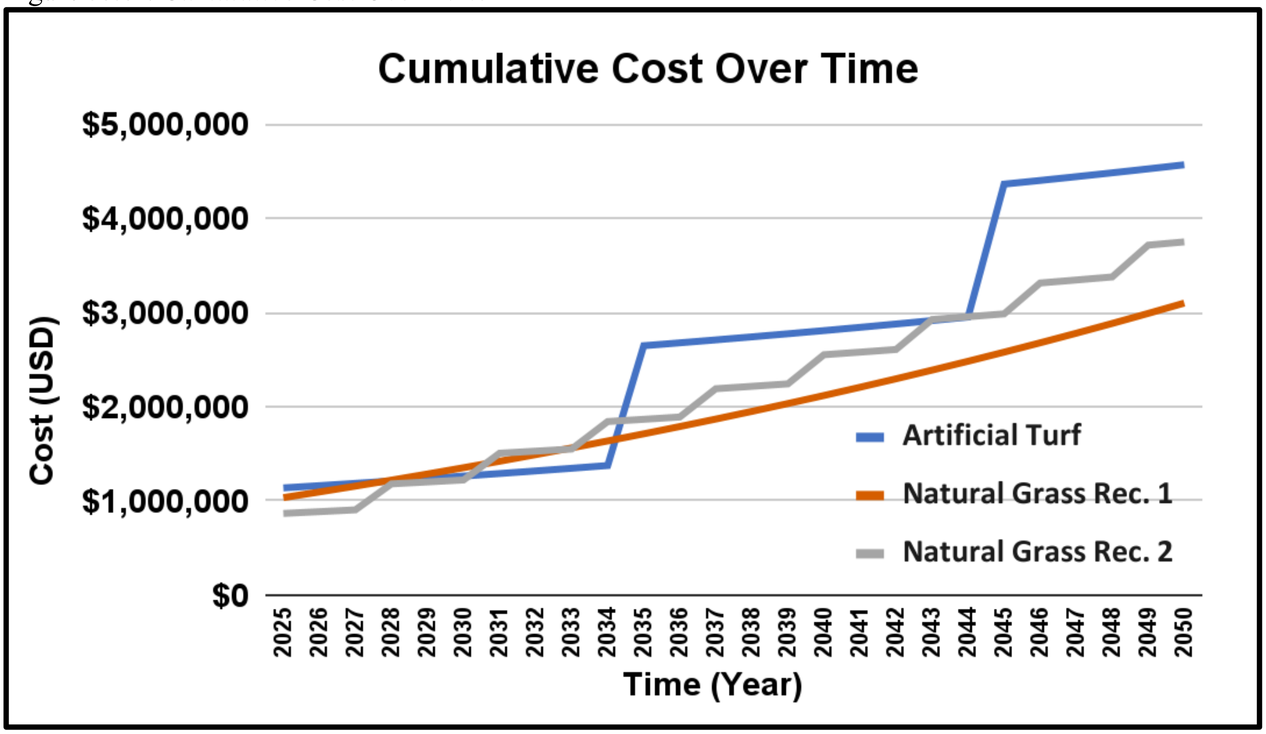
Installation Cost

Our Natural Grass Recommendation 1 is our primary proposal, has increased investment in maintenance and is assumed to not need reinstallation. Finally, our Natural Grass Recommendation 2 has minimal maintenance investment and will need to be resodded every 3-4 years. For our Artificial Turf Recommendation, the field needs to be reinstalled every 10 years and includes an additional allowance for drainage repair costs. **Specific installation items can be found in Appendix 2.**

Maintenance Cost

Labor costs are an important factor considered in all three scenarios of our analysis. However, they are not included in the cost-benefit analysis because it has been determined that recreation fields, whether they are natural grass or artificial turf, inherently rely upon municipal staffing. The labor hours required for maintenance and upkeep are generally equivalent between grass and artificial turf fields, making this cost consistent across all options. **Specific maintenance items can be found in Appendix 2.**

Figure 5.6.1: *Cumulative Cost Over Time*



The artificial turf line on the chart shows spikes every 10 years due to the reinstallation cost of $1,114,608, with inflation at a rate of 2.5% factored in over the years, leading to a gradual increase in costs. In contrast, Natural Grass Recommendation 1 has no spikes as an organic land manager will manage the field, eliminating the need for additional expenses and ensuring stable maintenance costs. Natural Grass Recommendation 2 exhibits slight cost increases every 3 years due to the sodding expense of $255,968, with the 2.5% inflation rate also considered, resulting in a gradual rise in sodding costs over time.

We calculated the inflation rate of 2.5% by averaging the inflation rates over the past ten years. This was done by adding the annual inflation rates for each of the ten years and then dividing the total by ten.

Limitations

The biggest limitation encountered during this research was finding accurate and reliable data for various cost factors, such as maintenance costs, installation costs, and replacement costs for both natural grass and artificial turf. The data from different sources often varied significantly, with each source potentially influenced by its own agenda. For example, manufacturers of artificial turf might present lower costs and higher benefits, while proponents of natural grass might do the opposite. Additionally, there is no standardized method for calculating these costs, as factors such as geographical location, field usage frequency, and local climate conditions can significantly impact them.

5.7 Hybrid Turf

Section Summary

Hybrid turf playing surfaces were a small aspect of this report, due to time constraints and the limited research available. Based on what was gathered, the reinforced root layer in hybrid turf allows for potentially more playing hours than natural grass. Playing hour benefits that are gained from hybrid turf, do not go as far as a fully artificial turf field. Though the percent make-up of hybrid turf that is synthetic is much smaller than an artificial turf field, these materials still carry risks to the environment and athletes that play on the fields.

The evolution of hybrid turf systems began with the Desso GrassMaster, an injected fiber system introduced in 1989 as the first of its kind on the market (The I, 2020). In the early 1990s, a mesh backing containing fibers was available, but it did not gain popularity until 2003 when textile-based systems began to compete with the Desso GrassMaster (The I, 2020). Around 20 years ago, a Dutch manufacturer developed a denser woven product similar to lightweight artificial turf, featuring an open mesh backing that allowed grassroots to penetrate deeply and anchor firmly (The I, 2020). Many products currently on the market are based on this design. Advances in technology have led to sophisticated machines that inject synthetic fibers into the soil, textile turf systems with biodegradable backings, and even shock absorption layers within the root zone (The I, 2020).

Hybrid turf is a primarily natural grass field with synthetic elements added that are meant to reinforce and stabilize the grass field, often at the root level. There are several main types of hybrid turf. Synthetic fibers included in the root zone, either when the fields were first growing, or tufted into the ground later. A horizontal mesh or carpet at the root zone. A horizontal mesh or carpet near the surface, ect (Dickson et al 2021)

The construction profile of the pitch for a hybrid turf is very well-planned and strategized. They are a 100/150mm gravel layer from formation with a drainage system to maintain even drainage across the pitch. Materials are laboratory-tested for size, hydraulic capacity, and also the level of bridging. The porous pavement system's lower root zone is the sand layer, which comprises a medium/fine angular gravel of 200mm thickness that is lab-analyzed. The root zone layer of the test section is simple: the first layer will be sand with the incorporation of organic material to form a 100mm uniform layer over the sand, size and hydraulic capacity conductivity test for sand, and local availability tested for sand. This stitched turf consists of 95% natural grass and 5% artificial fiber. This artificial fiber may have similar impacts to the environment as mentioned earlier in the report. The stitching goes for 7 inches to the base and 1 inch above the ground. Another, the SISgrass Lite variant has an adjustable stitching depth of 3. 5 inches. Different depths of stitching may affect the level of impact that these artificial materials have on the environment.

In contrast, a reinforced system includes a special support built into the soil where the grass will grow, making the surface stronger before the natural turf is planted. This reinforcement does not extend above the growing medium (SPORTENG, 2020). While both hybrid grass systems and reinforced profiles improve the stability of a sand profile and can be established as 'ready-to-play' products, there is a difference in the visual and functional benefits between the two (SPORTENG, 2020). When natural turf coverage is worn out due to high wear, hybrid turf is still able to provide a green look across the surface due to its protruding fibers. While reinforced profile does not contribute to the visual aesthetics, it does enhance stability of the field overall.

Some research has shown that root layer reinforcement has improved field quality, traction and field cover for Kentucky Bluegrass (Minner and Hudson, 2005), but Baker (1997) found that mesh had no impact on grass retention in cool season grasses and Dickson et al. (2021) similarly found no difference in green cover or most measures of quality of play for bermudagrass, a warm season natural grass.
Still, proponents of hybrid turf systems claim that, by rule of thumb, hybrid turf can get at least 1200 hours of playing time from the field, sometimes double that of natural grass (*Artificial Turf, Hybrid Turf or Natural Grass?*, n.d.). While meeting with hybrid turf experts they claimed that hybrid turf gets 3-4 times the playing hours of natural grass with their systems.

6. Recommendations

6.1 Environmental Impact

6.1.1 Natural Grass

With the comparison of water usage, emission rates, pollution, and runoff, we recommend natural grass when prioritizing environmental impact. To further mitigate environmental impacts from pollution and runoff, we recommend organic management without the use of synthetic pesticides. While the Township of Verona does not currently use synthetic pesticides, it is crucial to acknowledge how this may be a factor for future considerations. It is important to consider the best grass types for water conservation, such as tall fescue, that is also conducive to future climate predictions. Moreover, the construction of the natural grass field will be crucial in determining the overall environmental impact. For reduction of water usage, we recommend a recyclable water irrigation system as well as a drainage system to aid in runoff.

6.1.2 Artificial Turf

When considering artificial turf, it is important to examine every aspect of how artificial turf may impact the environment. Starting with the production of artificial turf, the use of non-renewable petroleum-based polymers can be improved upon by using renewable materials that rely on renewable energy sources to create the final artificial turf, however, there is currently no technology to reflect this improvement. Some organic options for the infill material include coconut fibers, cork, and sand (Zuccaro et al. 2024) which helps reduce the reliance on fossil fuels and lowers overall environmental impact. The impact of transportation can be decreased with local solutions in terms of proximity. Maintenance and lifetime of artificial turf must be balanced since the excess of maintenance outputs will cause a higher environmental impact, but the lack of such measures will lead to a shorter life span for the artificial turf. One of the biggest contributors to the high environmental impact of artificial turf is the end-of-life element. Since there are not adequate facilities to recycle artificial turf, they end up piling up in landfills which can cause years and years of unknown and unpredictable environmental consequences to both the natural environment and the people across the globe. The harmful effects of microplastics in the ocean can be felt from the seas to the land and in order to create a more sustainable planet, it is important to take steps away from the reliance on plastic. While there may be higher costs for more environmentally friendly options, it should be noted that there will be equal if more cost to the general public and governments in environmental damages and healthcare costs due to the issue of microplastic, chemical pollution, and more (Zuccaro et al. 2024).

6.2 Chemical Exposure

Based on the research and the data collected and when looking at risk of chemical exposure alone, we would recommend converting Centennial Field to a natural grass field due to the risk that elements of artificial turf pose to athletes. If artificial turf were to be used, we recommend critically evaluating and regulating the it's use, by particularly focusing on crumb rubber infill. Crumb rubber, made from recycled tires, contains hazardous chemicals and metals such as polycyclic aromatic hydrocarbons (PAHs), and heavy metals, which pose significant risks when ingested, inhaled, or through dermal contact. These substances have been linked to various health issues, including respiratory problems, skin irritation, and potential carcinogenic effects. Moreover, the blades of artificial turf often contain trace metals that can be harmful upon exposure. To mitigate and avoid these risks, it is advisable to look into and promote safer alternatives for infill materials. Options such as coconut husk and cork infills reduce the exposure to toxic chemicals and metals making them a safer choice for sports fields, and other areas where artificial turf is used extensively. It is also important to raise public awareness on the potential and known dangers of traditional and popular artificial turf components as this widespread information can significantly improve the environmental impact of the installations.

For maintaining natural grass, we recommend the use of organic fertilizers due to their benefits in promoting long-term soil health and sustainability. Organic fertilizers, which can be derived from mineral and rock products, animal products, and plant products, release nutrients slowly and improve soil organic matter (Panday et al. 2024). While their bioavailability can be unpredictable, the use of commercial fertilizers, many of which are byproducts of industries such as fisheries, livestock, and food processing, can contribute to a circular economy. In a circular economy, resources are reused, recycled, and repurposed, minimizing the need for new raw materials. This approach not only conserves natural resources but also reduces greenhouse gas emissions and energy consumption associated with the production of new materials. By incorporating waste products from various industries into agricultural practices as fertilizers, we can close the nutrient loop, ensuring that valuable nutrients are returned to the soil, enhancing its fertility and productivity.This utilization of waste products promotes sustainability by reducing waste and making efficient use of existing resources.

6.3 Injury

While lower extremity injury rates are most often found to be the same on artificial turf, some injury categories, such as foot and ankle injuries, have higher rates on artificial turf. It has been suggested that artificial turf has higher traction, resulting in more stress on players which is a possible explanation for the injury patterns seen. Additionally, many of the studies finding higher injury rates on natural grass are funded by the artificial turf industry. No clear link has been found between playing surfaces and the incidence or severity of concussions and other head trauma. Whether the playing surface is natural grass or artificial turf, care should be taken to maintain and keep it from getting too hard. This includes regular source hardness testing, maintaining an infill weight of greater than 6.0 pounds of infill per square foot in the case of artificial turf (Meyers, 2019), and aeration and sod replacement and overseeding in the case of natural grass. There is consensus in current research that artificial turf is more abrasive than natural grass. Studies on the subject, as with other injuries, are complicated by several factors, including that some players report changing their playing style on different surfaces, including being more hesitant to try moves, such as sliding tackles, on artificial turf that are more likely to result in abrasions. All of this taken together, well-maintained natural grass is more recommended than artificial turf when only thinking about injury rates. In any case, care should be taken to maintain the field.

6.4 Surface Heat
Based on the research and the data collected and when looking at temperature alone, we would recommend converting the Centennial field to a natural grass field due to the risk that artificial turf temperatures pose on adolescent athletes. Research on this topic shows artificial turf fields tend to reach much higher surface level temperatures when compared to natural grass. Surface temperature is not the only factor that needs to be considered, however, the disparity between the two surfaces is significant enough to drive our recommendations. When looking at the data we collected, there were some discrepancies between the measurements of the infrared thermometer and the HOBO data loggers. The magnitude of difference between playing surfaces' temperatures was much larger with the infrared thermometer data. The infrared thermometer readings were more similar to the values found in the literature. This difference may be attributed to the HOBO data loggers measuring values closer to the ambient temperature, rather than surface temperature. However, the overall trend suggested by sets of data remains the same. Higher surface temperatures are found on artificial turf surfaces when compared to natural grass. If an artificial turf field alternative is chosen a multifaceted approach should be implemented, combining accurate environmental monitoring, specific policies for coaches that incorporate both humidity and temperature when playing on artificial turf surfaces, and implementation of cooler turf products to protect athletes from the dangers of heat-related illnesses.

6.5 Playable Hours
Based on potential playable hours alone we would recommend artificial turf. Centennial Field is currently scheduled for 1348 hours of practice and gameplay yearly, less than half of the hours that artificial turf claims it can be used for annually. It is mixed use between soccer, lacrosse, football, baseball, softball, and field hockey and mainly hosts students from kindergarten through high school. Due to its young demographic and sports, it is unlikely to require round-the-clock use. These students are in school most of the day during sports seasons, and sports do not practice year-round. Case studies of nearby artificial turf fields show similar hours of use on their fields.
Case studies and data from nearby towns show some instances where natural grass fields are utilized successfully for similar numbers of hours to Centennial Field. Hopkins Field in Marblehead, for instance, is used for several hundred more hours than Centennial Field and is reportedly in good condition. The key here seems to be careful maintenance that maintains soil health and alleviates compaction. Verona fields are currently minimally maintained and a more comprehensive maintenance program would benefit all of its fields.

On average, natural grass fields were used less than Centennial Field. Additionally, nearby towns that have both artificial turf and natural grass use their natural grass less on average than their artificial turf. This implies that they feel able to get higher usage out of their artificial turf fields.
In conclusion, although artificial turf can be used for more hours annually without visibly balding; it will decrease in quality over time, and higher usage will likely result in a higher cost because it will accelerate the timeline of needed reinstallation. If natural grass is chosen for its other benefits, it is crucial that it is constructed and maintained well to allow for fast drainage, healthy grass, and to alleviate compaction. If proper care is taken, data indicates it may be possible for a natural grass surface to accommodate current, if slightly lower usage, but no guarantees can be made.

6.6 Cost Benefit Analysis
Based on costs alone we recommend a well-maintained natural grass field. While natural grass involves higher maintenance costs such as mowing, fertilizing, etc, artificial turf incurs greater expenses for installation and periodic replacement. The initial installation of artificial turf is significantly more

expensive due to the need for specialized materials and professional labor. Additionally, artificial turf requires reinstallation every 8 to 10 years to maintain its quality and safety standards, which adds to the long-term costs. On the other hand, natural grass, despite its ongoing maintenance requirements, can last indefinitely with proper care, potentially making it a more cost-effective option over an extended period.

7. Conclusion and Final Proposal

7.1 Conclusion

Based on our research, we recommend that the Township of Verona should replace Centennial Field with a natural grass field. Our research showed natural grass was more cost-effective in the long run, even when the high cost of hiring a professional was taken into account. This is due largely to the fact that artificial turf needs to be replaced approximately every ten years and would require additional stormwater infrastructure because of its impervious nature. A well-maintained natural grass field, even when maintained traditionally with synthetic fertilizers[3], was found to create much lower levels of pollution. A well maintained natural grass field, was also found to contain fewer compounds that harm the environment and human health and have lower levels of emissions over its lifetime.

Safety considerations as a whole also favor natural grass fields. Natural grass does not get as hot as artificial turf, decreasing the risk of heat exhaustion, and has generally similar or slightly lower injury risks in the categories researched. Although technologies exist that decrease the heat on artificial turf fields, they still do not decrease heat to levels comparable to natural grass fields. Additionally, such technologies are more expensive and have far higher emission rates than traditional artificial turf.

The main drawback of natural grass is the lower number of hours that it can be played on annually. There is no guarantee that a natural grass field installed at Centennial Field would be able to withstand its current level of usage and remain in good condition. There are recent cases of well-maintained natural grass fields that are able to withstand similar, or even higher levels of usage than Centennial Field. This suggests that it may be possible, so long as proper care is taken with the construction and maintenance of the field to allow for things like proper drainage, healthy soil, and healthy grasses, but no guarantees can be made. Natural grass also uses much more water over its lifetime, but other environmental considerations outweigh this issue.

7.2 Final Recommendations

Table 7.1 *Final Recommendations*

	NATURAL GRASS	ARTIFICIAL TURF

[3] Verona does not use any pesticides at the moment, which further decreases the environmental and health impacts of natural grass fields.

	Rec.1	Rec. 2	Rec. 1	Hybrid turf
CONSTRUCTION	Drainage Irrigation Recycle water	Drainage Irrigation	Drainage Stormwater infrastructure	Sand-based construction
TYPE / MATERIAL	Kentucky Bluegrass / Perennial Ryegrass Sand-based root zone Seeding	Tall fescue Native Soil Soding	Less abrasive artificial turf Natural artificial turf infill TPE cool infill	Stitched system
MAINTENANCE	Frequent aeration 3-5x a year Full-time - Organic land management	Short-term training for natural grass management Organic pesticides Organic considerations	Gmax / hardness testing Frequent infill replacement 6 lbs/sq ft	Aeration Spring Tining Dethatching Brushing

Natural Grass

Recommendation 1

Our main recommendation for the replacement of Centennial field is a natural grass field with the following specifications with considerations for environmental impact, chemical exposure, injury, heat, and cost. If a suitable company can be located, we recommend constructing the field with a drainage and irrigation system that will reuse water to both save on costs, but also to better the environment in overall water reduction. After the field is set up with proper systems in place, we recommend seeding instead of sodding to allow for grass type variation and reducing emissions and cost via reduction of transportation needs. For the grass type, we recommend Perennial ryegrass or Kentucky bluegrass. Both are cool season grasses which are recommended for New Jersey or similar climates. Kentucky bluegrass (*Poa pratensis*) is a fine textured grass that is able to form dense sod, crowd out weeds, and recover from heavy field usage (Cornell Grasses). Kentucky bluegrass is also able to be mowed to ¾ inches (Cornell Grasses) which would be ideal for field hockey fields that recommend shorter grass types. Possible issues that may arise for Kentucky bluegrass is the long time period of 12-18 months for sod development to the density needed for field usage (Cornell Grasses). Perennial ryegrass (*Lolium perenne*) is a medium textured grass that germinates within a few days and forms a usable turf field around 2-4 weeks (Cornell Grasses). This grass is best suited for sunny and well drained environments with less tolerance for shade and drought (Cornell Grasses). The preferred mowed height is 2 ½ inches which would be slightly above the recommended height of grass for field hockey. Perennial ryegrass tends to keep good color in the fall and spring time compared to Kentucky bluegrass (Cornell Grasses) which would be beneficial as those are peak playing seasons. With either option, it is recommended to use a sand based root zone which aids in compaction resistance, drainage, and aeration (Cale et al. 2000) or another type of soil mixture to help the native soil thrive in an active sports environment. In maintaining the field, we recommend hiring a full time organic land manager ensuring that the field is well maintained - such as frequent aeration, to prevent compaction and reduce injury as well as ensure necessary playable hours.

Recommendation 2

Our secondary recommendation is a natural grass field with a variety of tall fescue (*Festuca arundinacea* Schreb). Tall fescue is well adapted to New Jersey climates, grows pretty quickly, and establishes a strong root system, generating a decent wear tolerance (*Fs1186*, n.d.). Tall fescue is recommended to be mixed with Kentucky bluegrass to allow for best lateral spreading with a mixture somewhere between 80-95% tall fescue and 5-20% Kentucky bluegrass (*Fs1186*, n.d.). Tall fescue is also drought tolerant, providing proper construction and maintenance that limits soil compaction (*Fs1186*, n.d.). Tall fescue can ideally be mowed to a height around 2 inches, and as low as 1.5 inches which is within the range needed for field hockey, however, it should be considered that mowing below 2 inches will increase the likelihood of weed establishment (*Fs1186*, n.d.). We give the option of native soil here because it is more environmentally friendly, less energy intensive, and cheaper. Since the Township of Verona contains soils with high clay content, frequent aeration may be needed for proper maintenance. We recommend sodding instead of seeding as tall fescue takes a long time to establish itself and could make the fields unusable for multiple months. We still recommend robust drainage and irrigation systems both for field health, reduction of water usage, and for recovery time after rain. As opposed to a full time organic land manager, taking cost into account, we suggest the possibility of a short term field manager. This person could be hired at the beginning of the construction of the sports field to oversee the maintenance of the field and make sure it is properly established. Furthermore, they can stay on long enough to create a maintenance plan for the field and its specific needs, which can then be carried out by existing staff. We still recommend avoiding synthetic fertilizers and pesticides due to chemical exposure concerns, and with that being cautious when selecting organic fertilizers and pesticides because of the potential for higher concentrations of heavy metals and harmful substances in those varieties.

Artificial Turf
If the above natural grass options are not feasible or viable, we would recommend looking into a better version of artificial turf. This is artificial turf made with polyolefin. Polyolefin which is often referred to as polyethylene is designed to mimic the feel and texture of natural grass while still providing all the great benefits, particularly in terms of reduced abrasiveness. When we think of how much field time is needed by athletes, it is important to prioritize safety as games tend to get intense. A field that is able to provide the benefits of maximum playing hours while also reducing the intensity of impact, in terms of injury, is key. While there are other versions of artificial turf–such as those made with nylon, that may be cheaper and more durable, they have been found to be more abrasive than polyolefin artificial turf (Pronk et al., 2018). Another popular material used in artificial turf construction is polypropylene which is less expensive, but more abrasive (Pronk et al., 2018). While we recognize that synthetic polymers have high emissions, polyolefin is the better option when thinking of the interests of the safety of athletes on the field. When choosing infill for artificial turf we recommend natural options such as sand, cork, and coconut husk infill. Sand is a natural and non-toxic material, making it safer for children and the environment (Massey, 2020). Cork and coconut husk are renewable and biodegradable materials, this makes them an environmentally conscious choice that helps reduce overall emissions compared to crumb rubber infill (Massey, 2020). An alternative to the organic infill is the use of thermoplastic elastomer (TPE) infill. One of the key benefits of TPE is that it reduces the overall heat of the artificial turf field which can assist in reducing heat related illnesses (Singh et al, 2024). Although there is an extremely high emissions rate for TPE (Magnusson & Mácsik 2017), this is still a viable option for the safety of athletes due to its heat considerations. TPE stays flexible even at extremely low temperatures, down to -22°F, and stays cooler at higher temperatures (*TPE Infill* |, 2019). This is due to its unique design that allows heat to scatter more effectively. This helps in reducing surface heat and ensuring efficient playability. For effective maintenance of an artificial turf, hardness testing needs to be conducted frequently. This ensures that any necessary upkeep, such as infill replacement, is performed efficiently to reduce the impact on landing while playing and to prevent the motion of the ball from being affected by a hard surface. Additionally, maintaining the infill is crucial; it should be replenished periodically, with a recommended amount of 6 lbs/sq ft (Meyers M. C., 2019). This ensures the turf is properly cushioned, enhancing player safety.

Hybrid turf
Although not a primary recommendation, we acknowledge the option of a hybrid turf playing surface. If hybrid turf were to be considered, we recommend a product of the stitched hybrid variety. This system can create a more stable field and root structure in order to increase playing hours. Hybrid turf is also less abrasive than artificial turf and has about the same traction as natural grass, likely decreasing injury rates compared to artificial turf. However, a drawback compared to natural grass is the need to replace hybrid turf every 8-10 years, similar to the replacement time of artificial turf. We recommend a standard sand-based construction for the hybrid turf system, with maintenance practices similar to those for natural grass, including frequent aeration and soil health care. Additionally, hybrid turf-specific maintenance such as dethatching will be necessary.

Looking to the Future:
Although this report aimed to provide clarity on the current literature surrounding artificial turf and natural grass and guidance to the Township of Verona as they make their final decision regarding the future of the field, more work will still need to be done beyond this report. If Verona decides to follow our recommendation and opt for a natural grass field to replace Centennial Field, there will need to be diligent work done to ensure the success of the playing surface. They will have to find experts knowledgeable in modern natural grass sports fields construction and management to help them in every step of the process. They will also have to take into consideration the users of the field and how management practices will affect their sport experience. With time, we hope that this process can be made easier with the advancement of technology. If done right, we hope that Centennial Field can be looked to by other towns as an example of what can be achieved in natural grass fields in our modern age.

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9. Appendix

Appendix 1: *Environmental Impact Assessment Supplemental Charts*

Figure 9.1.1. *Natural Grass vs. Artificial Turf Environmental Impact Assessment*

	Artificial Turf	Natural Grass
Water Usage	~1.4-2mil gal water (production) 250,000gal water/year	0.5-1 mil gal water/year
Runoff	Impervious surface	Effective water infiltration
Pollution - chemicals	Microplastics, chemical/metal leaching	Pesticides, fertilizers, & maintenance
Emissions	~55.6 tCO2	~18.5 tCO2

Figure 9.1.2. *Environmental Impact Chart*

	Natural Grass	**Artificial Turf**

Chemicals / Metals	If used, chemical pesticides and herbicides can cause issues of pollution, human health risks, and overall impacts on the natural environment (Aktar et al., 2009).	PFAS, PAHs, VOCs, Zinc, and more found in artificial turf leads to chemical leaching, pollution, and human/animal health risks (Pavilonis et al., 2014) (Gaber, et al. 2023). (Bø1 et al. 2023).
Pollution	If used, pesticides and herbicides can leach into the ground and contaminate soil, water, and surrounding vegetation (Aktar et al., 2009).	Micro and nanoplastics are an issue regarding artificial turf. Supported by studies done in Spain, Switzerland, and the EU as a whole, microplastic pollution from turf largely - polypropylene (PP) and polyethylene (PE) can be found polluting rivers and oceans and harming marine life (William et al. 2023) (Itten et al. 2022) (Zuccaro et al. 2024)
Water usage	Natural grass fields require large amounts (~0.5 to 1 million gallons) of water for irrigation (Cheng et al., 2014).	Irrigation is not required for artificial turf, unless to cool to the field (Cheng et al., 2014). Water usage is intensive in the process of creating the turf (Bø1 et al. 2023). Production of the turf grass uses an estimated ~1.3-2 million gallons of water for a
Runoff	Natural grass is more effective at storing and slowing releasing infiltrated water, reducing the risk for flooding compared to artificial turfgrass. (Simpson & Francis 2021)	Artificial turf is thought to be impervious or semi-impervious, which results in increased runoff compared to natural grass. Long artificial turf performed less well than short artificial turf, emphasizing the need for design and operational considerations for turf (Simpson & Francis 2021).
Emissions	Maintenance and growing systems, such as mowing, and watering, reseeding, use greenhouse gas emissions (Cheng et al., 2014).	High CO2 emissions from artificial turfs occur during the manufacturing, production, transportation, installation, maintenance, and end of life such as incineration of fields (Bø1 et al. 2023).

Appendix 2: *Cost Breakdown by Line Item*

Figure 9.2.1. *Installation of Artificial Turf on Centennial Field (92120 square feet)*

Artificial Turf Installation Cost				
Description	**Quantity**	**Unit**	**Unit Price**	**Total**
Soil Erosion and Sediment Control	1	Lump Sum	$ 5,000	$ 5,000
Removal of Existing Turf and Infil	1	Lump Sum	$ 50,000	$ 50,000
Disposal of Existing Turf and Infil	1	Lump Sum	$ 50,000	$ 50,000
Install Coolplay w/ Infill	92120	Square Feet	$ 7	$ 644,840
Stormwater Infrastructure	1	Lump Sum	$ 150,000	$ 150,000

Finishing Stone Repair	50	Cubic Yard	$ 80	$4,000
Drainage System Repair	1	Lump Sum	$ 25,000	$ 25,000
Estimate				$928,840
20% Contingency				$ 185,768
Total Estimate				$ 1,114,608

The majority of line items in our installation cost tables were estimated by a local engineering firm that works with Verona, looking at the current state and size of Centennial Field. The preliminary cost estimates were provided for discussion only. Actual quantities may vary due to existing as-built and subsurface conditions; to be reflected by a final detailed engineering investigation and design (Davis, 2024).

Stormwater Infrastructure: New Jersey considers artificial turf to be an impervious surface. The newest version of Verona's stormwater municipal ordinance requires developments over 1 acre (Centennial is well over 2 acres) to have sufficient stormwater management infrastructure (Township of Verona Municipal Code §451). We consulted with a civil engineer working closely with the Township and estimated an investment of about $150,000 to build stormwater infrastructure for Centennial Field.

Finishing Stone Repair: When reinstalling an artificial turf field there are often depressions found on the stone due to shallow infills. We sat with an engineer and estimated a $25,000 cost for this (if and where directed).

20% Contingency: The 20% contingency is based on costs to study, design and manage the implementation of the project. As these recommendations are at an early stage, we believe that percentage is sufficient to encapsulate these additional costs.

After consulting with an engineer working in Verona, we decided to alot an allowance for Additional Drainage Costs of $100,000 every 10 years due to the additional wear and tear of the drainage system.

Figure 9.2.2. *Installation of Natural Grass Recommendation 1 on Centennial Field (92120 square feet)*

Natural Grass (Recommendation 1) Installation Cost				
Description	**Quantity**	**Unit**	**Unit Price**	**Total**
Soil Erosion and Sediment Control	1	Lump Sum	$ 5,000	$ 5,000
Removal of Existing Turf and Infil	1	Lump Sum	$ 50,000.00	$ 50,000
Disposal of Existing Turf and Infil	1	Lump Sum	$ 50,000.00	$ 50,000
Excavate and Removal of Finishing Stone, 2" Thick	569	Cubic Yard	$ 50.00	$ 28,450
Excavate and Removal of Clean Stone, 2" Min	1137	Cubic Yard	$ 50.00	$ 56,850
Nonwoven Geotextile Fabric	10236	Square Yard	$ 5.00	$ 51,180

Topsoil Spreading and 2% Regrading, 8" Thick Min	10236	Square Yard	$ 25.00	$ 255,900
Seeding	92120	Square Feet	$ 0.45	$ 41,454
Fertilizing and Seeding	3000	Square Yard	$ 3.00	$ 9,000
Straw Mulching	3000	Square Yard	$ 3.00	$ 7,500
Irrigation System	1	Lump Sum	$ 40,000.00	$ 40,000
Subsurface Irrigation Management	1	Lump Sum	$187,500	$187,500
Drainage System	1	Lump Sum	$ 25,000.00	$ 25,000
Final Clean-up	1	Lump Sum	$ 5,000.00	$ 5,000
Estimate				$ 812,834
20% Contingency				$ 162,567
Total Estimate				$ 975,401

The majority of line items in our installation cost tables were estimated by a local engineering firm that works with Verona, looking at the current state and size of Centennial Field. The preliminary cost estimates were provided for discussion only. Actual quantities may vary due to existing as-built and subsurface conditions; to be reflected by a final detailed engineering investigation and design. (Davis, 2024)

Seeding: For our primary recommendation, we opted for seeding with Kentucky bluegrass due to its durability and suitability for the region's climate. We identified Kentucky bluegrass as a top choice for providing a lush and resilient lawn. To estimate the cost, we calculated the expense based on a rate of $0.45 per square foot. Given the area of Centennial, which spans 92,000 square feet, the total cost amounted to $41,400. To ensure we have a sufficient budget for any unforeseen expenses or additional requirements, we rounded this figure up to $45,000. (Miguelez, 2022)

Subsurface Irrigation System: In order to extend the life of a natural grass field and increase the playing hours available we recommend using a subsurface irrigation system that recycles water back into the aquifer system. Based on consultations with vendors of products that provide this service, we estimated this cost to be $187,500.

Figure 9.2.3. *Installation of Natural Grass Recommendation 2 on Centennial Field (92120 square feet)*

Natural Grass Recommendation 2 Installation Cost				
Description	**Quantity**	**Unit**	**Unit Price**	**Total**
Soil Erosion and Sediment Control	1	Lump Sum	$ 5,000	$ 5,000
Removal of Existing Turf and Infill	1	Lump Sum	$ 50,000.00	$ 50,000
Disposal of Existing Turf and Infill	1	Lump Sum	$ 50,000.00	$ 50,000
Excavate and Removal of Finishing Stone, 2"Thick	569	Cubic Yard	$ 50.00	$ 28,450
Excavate and Removal of Clean Stone, 2" Min	1137	Cubic Yard	$ 50.00	$ 56,850

Nonwoven Geotextile Fabric	10236	Square Yard	$ 5.00	$ 51,180
Topsoil Spreading and 2% Regrading, 8" Thick Min	10236	Square Yard	$ 25.00	$ 255,900
Soding	10236	Square Yard	$ 12.00	$ 122,832
Fertilizing and Seeding	3000	Square Yard	$ 3.00	$ 9,000
Straw Mulching	3000	Square Yard	$ 3.00	$ 7,500
Irrigation System	1	Lump Sum	$ 40,000.00	$ 40,000
Drainage System	1	Lump Sum	$ 25,000.00	$ 25,000
Final Clean-up	1	Lump Sum	$ 5,000.00	$ 5,000
Estimate				$ 706,712
20% Contingency				$ 141,342
Total Estimate				$ 848,054

The majority of line items in our installation cost tables were estimated by a local engineering firm that works with Verona, looking at the current state and size of Centennial Field. The preliminary cost estimates were provided for discussion only. Actual quantities may vary due to existing as-built and subsurface conditions; to be reflected by a final detailed engineering investigation and design. (Davis, 2024)

Figure 9.2.4. *Installation of Natural Grass Recommendation 2- 2nd Instillation*

Natural Grass Recommendation 2 - 2nd Installation Cost				
Description	**Quantity**	**Unit**	**Unit Price**	**Total**
Soil Erosion and Sediment Control	1	Lump Sum	$ 5,000	$ 5,000
Topsoil Spreading and 2% Regrading, 8" Thick Min	2559	Square Yard	$ 25.00	$ 63,975
Sodding	10236	Square Yard	$ 12.00	$ 122,832
Fertilizing and Seeding	3000	Square Yard	$ 3.00	$ 9,000
Straw Mulching	3000	Square Yard	$ 3.00	$ 7,500
Final Clean-up	1	Lump Sum	$ 5,000.00	$ 5,000
Estimate				$ 213,307
20% Contingency				$ 42,661
Total Estimate				$ 255,968

The majority of line items in our installation cost tables were estimated by a local engineering firm that works with Verona, looking at the current state and size of Centennial Field. The preliminary cost estimates were provided for discussion only. Actual quantities may vary due to existing as-built and subsurface conditions; to be reflected by a final detailed engineering investigation and design. (Davis, 2024) Resodding would need to be performed approximately every three years to maintain the quality and appearance of the turf. This regular resodding ensures the grass remains lush, healthy, and free from issues such as bare spots, weed infestations, and disease.

Figure 9.2.5. *Maintenance of Artificial Turf on Centennial Field (92120 square feet)*

Artificial Turf (Annual Maintenance)	
Description	**Estimate**
Management of Stormwater Devices	$ 8,000
Upkeep of existing equipment (Sweeper/Broom/Painter/Groomer)	$ 3,000
Acquisition of New Maintenance Equipment (Magnet, Rollers, Etc.)	$ 1,500
Painting (If & Where Directed)	$ 1,000
Disinfection	$ 220
GMAX Testing	$ 2,750
Grooming Contractor	$ 6,800
Total Annual Maintenance	$ 23,270

All tools and equipment listed above are crucial to maintaining either artificial turf or natural grass (Wolfson, 2015).

Management of Stormwater Devices: If an artificial turf alternative is selected, the required stormwater infrastructure will need to be maintained and cleaned about twice a year. This cleanout would cost about $4000 based on our meetings with engineers. This adds up to a total of $8000 per year.

Acquisition of New Maintenance Equipment: Some of the equipment used to maintain artificial turf fields in Verona include a Hurricane stand up blower, Toro 3 wheel machine, groomer, and a John Deere 3620 machine with a 4 ft broom. Based on meetings with the town's recreation department an investment of about $5000 every 5 years for purchasing new equipment comes to about $1000 per year.

GMAX Testing: Based on our meeting with the recreational department of Verona, we were provided with information regarding GMAX (hardness) testing. The total annual township cost for GMAX testing is $8250. It's important to note that this cost covers 3 out of 3 fields so we had to divide it up into three costs to which we came to the conclusion of $2,750.

Grooming Contractor: The Township of Verona employs a grooming contractor that helps maintain their artificial turf fields. The cost of this contract is about $17,000 according to the Verona recreation department. The contractor works on all three artificial turf fields in Verona, so we reduced this number to about 40% or $6,800.

Upkeep of Equipment: The upkeep of equipment involves various costs, including repairs, fuel, and the purchase of new equipment to replace worn-out items. These expenses are essential to ensure that all machinery remains in optimal working condition and continues to function efficiently over time.

Figure 9.2.6. *Maintenance of Natural Grass Recommendation 1*

Natural Grass Recommendation 1 (Annual Maintenance)	
Description	**Estimate**
Irrigation	$ 6,000.00
Equipment For Irrigation	$ 3,000.00
Organic Land Contractor	$ 50,000.00
Total Annual Maintenance	$ 59,000.00

During our background research, we discovered the costs associated with irrigation and equipment (Wolfson, 2015).

Organic Land Contractor: After reaching out to an organic land contractor based in New York who also operates in New Jersey, we were provided with a cost of $0.33 per square foot for maintenance annually. We then multiplied this rate by the size of Centennial (92,000 square feet), resulting in a total cost of $30,360 annually. This estimate does not include expenses for grading, preparation, soil, and other related items. Taking these into account resulted in an estimated $50,000 annually (Grey, 2024).

Figure 9.2.7. *Maintenance of Natural Grass Recommendation 2 on Centennail Field*

Natural Grass Recommendation 2 (Annual Maintenance)	
Description	**Estimate**
Irrigation	$ 6,000
Equipment For Irrigation	$ 3,000
Equipment Upkeep (Mower, Groomer, Aerator, Painter, Fertilizer)	$5,000
Painting/Removal	$800
Top Dressing (TopSoil)	$ 1,000
Organic Fertilizers	$ 1,200
Organic Pesticides	$650
Sod Replacement	$833
Total Annual Maintenance	$18,483

During our background research, we discovered the costs associated with irrigation, equipment and other line items.(Wolfson, 2015)

Upkeep of Equipment: The upkeep of equipment involves various costs, including repairs, fuel, and the purchase of new equipment to replace worn-out items. These expenses are essential to ensure that all machinery remains in optimal working condition and continues to function efficiently over time

Appendix 3: *Surface Heat and Infrared Thermometer Data Collection & Advisory Charts*

Table 9.3.1 *Infrared Thermometer Data Collected for June 18, 2024*

Centennial	Veterans	Ambient

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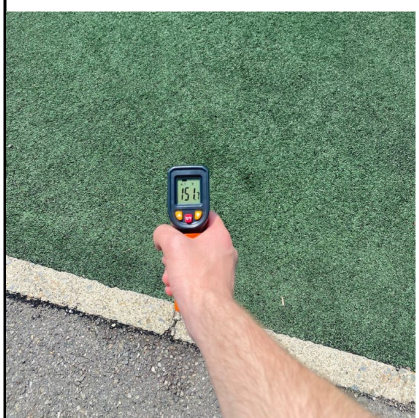
<td></td>
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Table 9.3.2 *Infrared Thermometer Data Collected for June 24, 2024.*

Centennial	Veterans	Liberty	Ambient

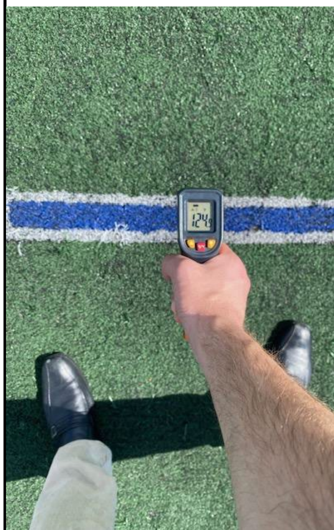
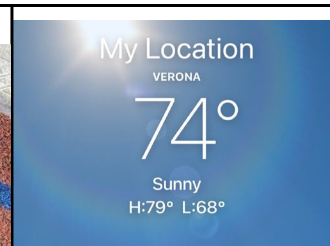
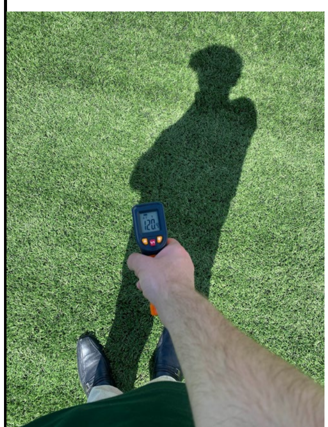
			My Location VERONA 74° Sunny H:79° L:68°
			My Location VERONA 74° Sunny H:79° L:68°

Table 9.3.3 *Infrared Thermometer Data Collected for July 17, 2024.*

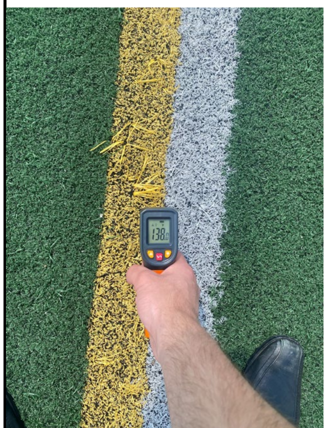
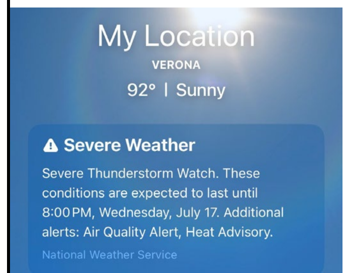
Centennial	Veterans	Liberty	Ambient
			

Table 9.3.4 *Rutgers Youth Sports Council Heat Advisory Policy*

Safety zone	What to do
Safe Zone	• Exercise as usual. • Safe to exercise outdoors.
Alert Zone	• Decrease your exercise intensity (slow your walking pace). • Watch for signs (such as shortness of breath, increased tiredness).
Danger Zone	• No outdoor exercise. • Exercise in an air conditioned environment only.
Emergency Zone	• Avoid going outdoors.

Table 9.3.4 was provided by the Verona Parks and Recreation Department

Figure 9.3.5 *Rutgers Youth Sports Council Heat Advisory Graph*

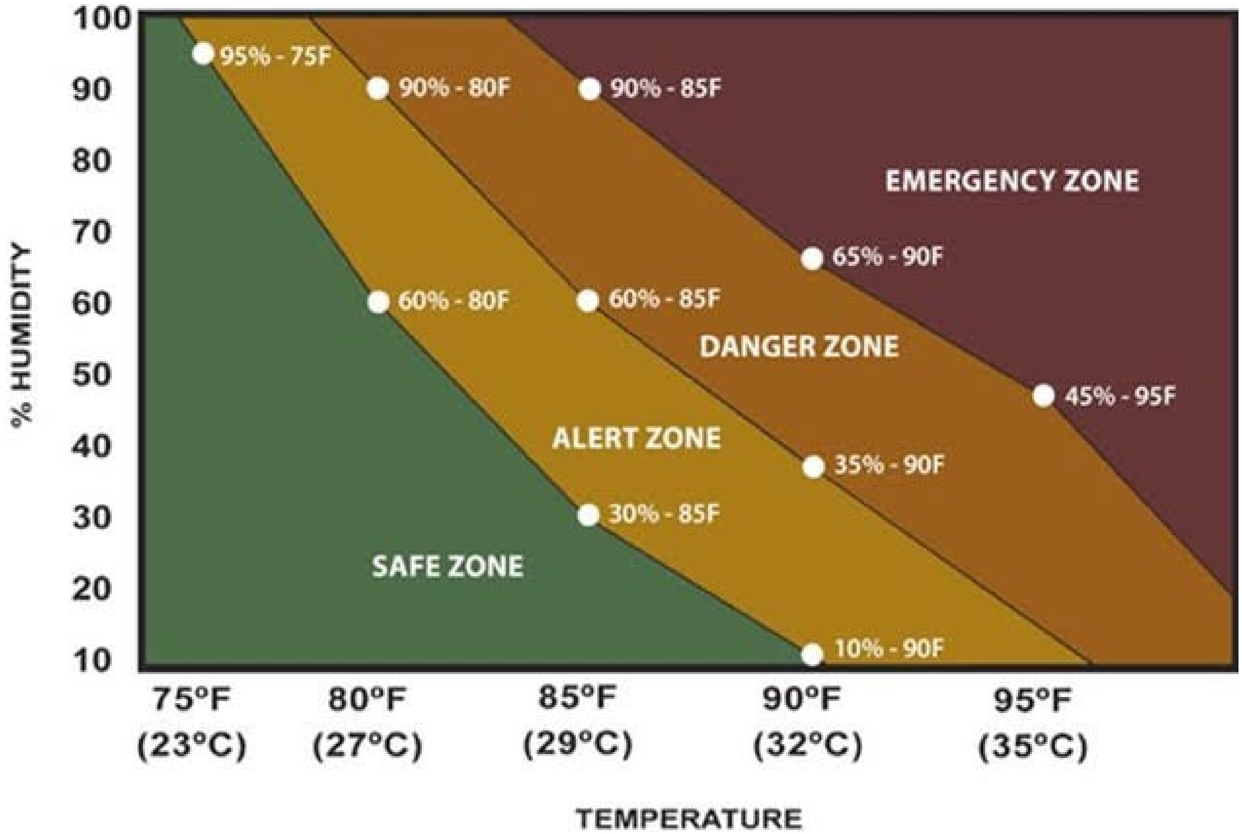


Figure 9.3.5 was provided by the Verona Parks and Recreation Department.

Appendix 4 : *Final Breakdown*

Figure 9.4.1. *Structure of Artificial Turf and Natural Grass*

	Artificial Turf	Natural Grass
Environmental Impact	High overall environmental impact	Low-med overall environmental impact
Chemical Exposure	High hazardous chemicals	Low hazardous chemicals
Injury	Equal overall; Higher ankle and foot injuries; Higher abrasions	Equal overall lower extremity injury
Surface Heat	High surface heat	Low surface heat
Playable Hours	More playable hours	Less playable hours
Cost Benefit	More costly (25 year period)	Less Costly (25 year period)