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Evaluation of Turfgrass Replacement Options: Artificial Turf

Elisabeth M. Jenicek and Amanda T. Rodriguez

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Evaluation of Turfgrass Replacement Options: Artificial Turf

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Abstract

Artificial turf, long in use on athletic fields in the civilian sector, is finding its way to military installations. This technology can help to meet both training and aesthetic requirements without the irrigation footprint associated with most natural turf fields. With the increased use of artificial turf, particularly in drought-plagued regions, emerge concerns about its potential adverse effects. There is a need for additional information, both on technical performance and cost-benefit analysis, to support decisions about use of artificial turf at Army installations. This work was undertaken to research costs and benefits of both artificial and natural turf materials, and to develop guidelines for making design decisions. This study examined technical, financial, and performance data and recommends best practices for the use of artificial turf.

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Preface

This study was conducted for the Office of the Assistant Secretary of the Army, Installations, Energy, and Environment (OASA[IE&E]), via Military Interdepartmental Purchase Request (MIPR) No. 11097857, “Evaluation of Turfgrass Replacement Options.” The technical monitor was Dr. Marc Kodack, OASA(IEE).

The work was managed and executed by the Energy Branch of the Facilities Division, Construction Engineering Research Laboratory, Engineer Research and Development Center (ERDC-CERL). At the time of publication, the Chief of the Energy Branch was Ms. Giselle Rodriguez and the Chief of the Facilities Division was Mr. Donald Hicks. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti and the Director was Dr. Lance D. Hansen.

Special appreciation is owed to the installation points of contact who shared with this study their invaluable experience with both natural and artificial turf. Appreciation is also extended to Ms. Theresa Smith, of the U.S. Army Garrison Fort Bragg; Mr. Michael Rubbino, of the U.S. Military Academy at West Point; Mr. Thomas Serensits of the Penn State Sports Surface Research Center; Ms. Sandra Roesler and Mr. Tyler McKinney, of the Champaign Unit 4 School District; and Mr. Jonathan Huard, of FieldTurf.

COL Teresa A. Schlosser was Commander of ERDC, and Dr. David W. Pittman was the Director.

1 Introduction

1.1 Background

Landscape irrigation is a substantial water demand on Army installations. During fiscal year 2013 (FY13), landscape irrigation represented over 75% of industrial, landscape, and agricultural (ILA) water demand on U.S. Army Installation Management Command (IMCOM) installations. This still is a likely underrepresentation of total landscape irrigation water demand since ILA water reporting is often incomplete and inaccurate (PNNL 2014). Furthermore, according to the Department of Defense's (DoD) *Memorandum on Water Use for Landscape Architecture on DoD Installations/Sites*, "gardening and lawn care accounts for the majority of ... seasonal increase" in peak water demand during the summer (DoD 2017).

Federal, DoD, and Army policy and standards mandating reductions and limitations in landscape irrigation water use have acted as an impetus for Army installations to reduce landscape water use and rethink landscaping practices and mediums. Replacing natural grass with other landscape surfaces is one solution to reducing or eliminating a major, and often non-essential, water end use. Xeriscaping, for example, addresses water reduction demands but may not be practical for all landscape applications, such as parade grounds and athletic fields.

Artificial turf, long in use on residential lawns and athletic fields in the civilian sector, is finding its way onto military installations. This technology has the potential to meet water reduction standards while still fulfilling aesthetic and practical usage requirements. As Army installations consider this investment, there is a need for additional information, both on technical performance and maintenance and life-cycle costs, to inform decisions about use of this technology on Army installations. The purpose of this report is to present current understanding of artificial turf technology and evaluate its applicability as a natural turf retrofit option.

1.2 Objectives

The objectives of this work were to evaluate the applicability of artificial turf as a retrofit alternative to natural turf for use on athletic fields and parade grounds on Army installations based on:

1. water conservation
2. cost
3. access to fields
4. health/environmental implications

A further objective of was to provide installation landscape managers with a sound set of criteria upon which to base their decisions to retrofit natural turf fields with artificial turf.

1.3 Approach

The objectives were completed through the following steps:

1. Conduct a literature review of relevant landscape irrigation water policy, current artificial turf technologies, and health and environmental risks associated with use of artificial turf.
2. Evaluate the effectiveness of artificial turf as compared to natural turf. This shall include a cost-benefit analysis and any positive and negative qualities of each alternative surface.
3. Interview select Army installations and civilian organizations with artificial turf applications for technical, financial, and performance data and lessons learned, as available.
4. Prepare a report to document the steps outlined above including a discussion of the planning information required to decide about natural grass retrofit, a narrative description of best practices, examples of applications, a cost-benefit analysis, and recommendations for use of these technologies.

1.4 Scope

1.4.1 Assumptions and limitations

1.4.1.1 Existing research

It is difficult to draw conclusions based on published research related to artificial turf. Studies addressing some of the factors that this report investigated

were not available. Limited studies were available for other factors. Additionally, some of the references cited in this report are from artificial turf manufacturers and industry groups, rather than scientific research studies.

1.4.1.2 Case studies

Documentation of case studies in this report relied on knowledge of artificial turf installations as well as access to information. Increasing the number of case studies would be beneficial to comparisons between artificial and natural turf surfaces.

1.4.1.3 Life-cycle cost analysis

This study was unable to document a life-cycle cost analysis (LCCA) that was used in selection between artificial turf and natural turf, or selection between suppliers of different types of artificial turf. Recommendations for conducting an LCCA are based on general guidance and on the wider body of information and research drawn on for this report.

1.4.2 Additional application

The results of this project will inform decisions on the feasibility and appropriateness of retrofitting natural grass with artificial turf, which will differ depending on an application's budget, hours and type of intended usage, and climate. The focus was on large applications, such as sports fields and parade grounds; however, the conclusions are applicable to smaller sites such as general building landscaping for aesthetics.

1.5 Mode of technology transfer

It is anticipated that information derived from this project will support changes to policy and specifications. Results of this work will be disseminated in journal articles in such publications as the *Public Works Digest*, *Corps Environment*, and the *Army Engineer*. This project will be coordinated with the Assistant Chief of Staff for Installation Management (ACSIM), IMCOM, U.S. Army Materiel Command (AMC), U.S. Army Corps of Engineers (USACE), and U.S. Army Reserves (USAR).

2 Overview of Landscape Irrigation Water Use Policies

Policies developed to minimize potable water use and reduce overall water consumption for landscape irrigation purposes have motivated Army water managers to either entirely abandon irrigating landscapes of non-critical functions, to develop sophisticated irrigation systems sourcing water onsite, or to switch to landscape surfaces that demand little to no additional irrigation. Cutting off irrigation for landscapes is a straightforward, cost-saving strategy to comply with water use elimination or reduction standards. However, it is not practical in all cases to simply abandon irrigation. For example, administrative buildings may require some aesthetic landscaping; athletic fields typically require additional irrigation to maintain them in a functional, safe condition.

This chapter reviews key federal, DoD, and Army policies that limit the type and amount of water allowed for landscape irrigation and that encourage installations to rethink irrigation and landscaping practices. It also presents key policies to consider when installing artificial turf as a landscape alternative. Note that this summary does not include state and local regulations and policies, which, if they exist, may affect water use reduction requirements and necessary steps in the design and installation of an artificial turf field.

Nevertheless, installations can pursue reasonable alternatives that comply with the policies outlined in this chapter by developing irrigation systems that draw water from an onsite source or by re-landscaping using plants, techniques, and surfaces that require little to no additional irrigation.

2.1 Landscape irrigation and design policies

2.1.1 Federal policy

Federal landscape irrigation water use policy originates from several Executive Orders (EOs). Table 2-1 lists recent EOs that include standards for reducing potable water use and, when applicable, ILA water consumption.

Table 2-1. Major Federal mandates for landscape irrigation water use.

Mandate	Area	Requirement(s)/Performance Target(s)
EO 13423, Jan 2007 (Revoked)	Water consumption	Reduce consumption by 2% annually for 16% reduction by FY15 (FY07 baseline)
EO 13514, Oct 2009 (Revoked)	ILA water consumption	Reduce consumption by 2% annually for 20% reduction by FY20 (FY10 baseline)
EO 13693, Mar 2015 (Revoked)	ILA water consumption	Reduce consumption by 2% annually for 30% reduction by FY25 (FY10 baseline)
EO 13834, May 2018	Water consumption	Reduce potable and non-potable water consumption when cost-effective

EOs have addressed specific water reduction standards, typically by increasing and extending goals, by defining types of water consumption, and by limiting the sources that can be used, depending on the end use. Implementation guidance developed for EO 13514 (White House 2009), which continued as guidance for EO 13693 (White House 2015), defines ILA water sources as non-potable water either purchased or collected on site from freshwater sources (CEQ 2013). Additionally, reduction standards for ILA water measures consumption by total combined volume of water consumed rather than water use intensity (i.e., gallons per gross square feet).

The most recent EO mandating water use reductions, EO 13834, *Efficient Federal Operations* (White House 2018), excludes the distinction between ILA and potable water consumption and eliminates per annum goals set by previous EOs (see Table 2-1). However, the guidance for (revoked) EO 13693 must still be followed until guidance for EO 13834-specific implementation instructions is developed (FedCenter 2018).

2.1.2 DoD policy

DoD policies that specify reductions in landscape irrigation water consumption (see Table 2-2) are more comprehensive and restrictive than those standards enacted by federal policy. Two of the DoD's Unified Facilities Criteria (UFC) documents provide technical requirements and guidance regarding landscape irrigation design and water use. UFC 3-201-02, *Landscape Architecture* (NAVFAC 2009), promotes switching to non-potable water sources and reducing water consumption via the installation of water-efficient landscape material and irrigation systems (2009).

Table 2-2. Major DoD mandates for landscape irrigation water use.

Mandate	Area	Requirement(s)/Performance Target(s)
UFC 3-201-02, <i>Landscape Architecture</i> (NAVFAC 2009)	Water consumption	Install water-efficient irrigation systems Maximize use of water-efficient plant material
	Water source	Non-potable water sources for landscape irrigation
UFC 1-200-02, <i>High Performance and Sustainable Building Requirements</i> , 2013	Outdoor water consumption	Reduce consumption by a minimum of 50% Comply with UFC 3-201-02 (See above) When life-cycle cost-effective, comply with ASHRAE 189.1 section 6.3.1 and either section 6.4.1 or 6.5.1
Memo on Water Use for Landscape Architecture on DoD Installations/Sites (DoD 2017)	Landscape water consumption	Reduce or eliminate potable water consumption for landscape maintenance

UFC 1-200-02, *High Performance and Sustainable Building Requirements* (NAVFAC 2018), mandates a reduction of outdoor water use by at least 50% as well as compliance with UFC 3-201-02 and sections of American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 189.1 when life-cycle cost-effective (2013).

The *Memorandum on Water Use for Landscape Architecture on Department of Defense Installations/Sites* (DoD 2017) is a major DoD mandate regulating landscape water use. This memorandum makes reducing or eliminating “the use of potable or domestic water for purposes of landscape architecture maintenance” and applying water-efficient landscape design the policy of the Department.

2.1.3 Army policy

Army-specific policies largely mirror federal and DoD mandates (Table 2-3).

Table 2-3. Major Army mandates for landscape irrigation water use.

Mandate	Area	Requirement(s)/Performance Target(s)
Army Regulation (AR) 420-1, <i>Army Facilities Management</i> (HQDA 2008) (Revised 2012)	Landscape irrigation	Use reclaimed or recycled water
Memo on Energy and Water Goal Attainment Responsibility Policy for	ILA water consumption	Reduce consumption by 2% annually for 30% reduction by FY25 (FY13 baseline)

Mandate	Area	Requirement(s)/Performance Target(s)
Installations (ASA[IE&E] 2017a)	Irrigation	Prohibits irrigation except where specifically required by Army policy Areas that require irrigation must only use alternative water, not outdoor potable water
Memo on Sustainable Design and Development Policy Update (ASA[IE&E] 2017b)	Outdoor water consumption	Reduce consumption by a minimum of a 50% reduction
	Landscape design	Comply with ASHRAE 189.1-2014 section 6.3.1 and either 6.4.1 or 6.5.1

2.2 Other policies that may affect use of artificial turf

Provisions of several Public Laws may affect the applicability, design, and installation of artificial turf systems on Army installations (Table 2-4). For example, the provisions of the Clean Water and Endangered Species Acts may apply to artificial turf materials in cases where it has not been thoroughly established that those materials have no chemical leaching potential that may impact water quality and affect organisms that rely on that water (see section 4.4.2). Proper sourcing and choice of materials is the best way to avoid such unknown chemical consequences.

Table 2-4. Other policies that may affect the use of artificial turf.

Mandate	Area	Requirement(s)/Performance Target(s)
Federal Clean Water Act of 1977	Chemical discharge, water quality	Regulates discharge of material into waters of the United States
Endangered Species Act of 1973	Biodiversity impacts	Regulates actions that may have an impact on rare plants and animals
Energy Independence and Security Act of 2007, section 438	Hydrology and stormwater runoff	Requires federal development or redevelopment projects larger than 5,000 sq ft to maintain or restore predevelopment hydrology
Federal Agency Implementation of Water Efficiency and Management Provisions of EO 13514 (CEQ 2013)	ILA water conservation	Actions for reducing consumption should consider variability in climate

Both 42 USC* 17094 (*Storm Water Runoff Requirements for Federal Development Projects*) and section 438 of the Energy Independence and Security Act of 2007 (EISA 2007) require federal development or redevelopment projects larger than 5,000 sq ft to maintain predevelopment hydrology. This should guide the design of the drainage system beneath fields that exceed that size in area.

* U.S. Code (USC)

Regional climate should be considered to determine the functionality and water-saving potential of artificial turf systems. As discussed in section 4.1, surface temperatures of artificial turf, which are significantly higher than those of natural grass, can cause athletes to suffer heat-induced illnesses. Fields may need to be repeatedly inundated with water to regulate their surface temperatures to maintain them in a functional, safe condition for use during periods of high temperature. This can significantly increase water demand. The *Federal Agency Implementation of Water Efficiency and Management Provisions of EO 13514* (White House 2009) mandates that actions intended to reduce ILA water consumption consider the variability in climate (2013).

3 Artificial Turf Technology

3.1 History and development

3.1.1 Brief history of artificial turf

Artificial turf is a carpet of synthetic fibers designed to mimic natural grass. It was first developed in the early-1960s by the Chemstrand Company, a subsidiary of Monsanto (Premier Artificial Turf 2015). Funded by the Ford Foundation, Chemstrand researched the development of a playing surface that replicated natural grass to increase physical fitness in young people, particularly those living in urban areas (AstroTurf 2018). Originally called ChemGrass, the product was renamed and popularized as AstroTurf after its installation in the Houston AstroDome in 1966. It was initially used heavily for sports and athletic purposes, and, in the 1990s, use was expanded to residential functions (Kuznia 2015). Since its development, artificial turf design has been refined and specialized to decrease injuries, accommodate specific uses, and appeal more to aesthetics.

3.1.2 Product development

Currently, three formally recognized generations of artificial turf products are distinguished by recognized standards and differentiated by both the material composition and improved designs for safety and playability. First generation artificial turf (1G), recognized also as AstroTurf, is made of tightly wound nylon fibers, includes no infill material, and is attached to a foam backing (SGW 2013, TigerTurf 2018). First generation turf material is stiff and constraining, resulting in higher incidents of ankle injuries compared to natural turf (Serentsits 2012).

Second generation artificial turf (2G), introduced in the 1970s, was an attempt to better mimic the flexibility and appearance of natural turf. This generation is made with polypropylene fibers attached to a carpet-like backing and infilled with sand (SGW 2013, TigerTurf 2018). This generation is successful for field hockey playing surfaces but is not as suitable for sports like soccer when compared to the performance of natural turf (SGW 2013).

Third-generation artificial turf (3G), introduced in the mid-1990s, is the most widely used artificial turf product currently. It is distinguished by its infill, a layer of crumb rubber over a layer of sand. The loose and elastic crumb rubber allows for more flexibility and reduces friction between

cleats and the playing field while still providing enough traction (Synthetic Green Warehouse 2013). This has significantly reduced the incidence of ankle injuries since it allows greater joint flexibility (Serentsits 2012). Most fibers are made of a mixture of polyethylene attached to a carpet-like backing, resulting in a durable, softer, and more natural-looking turf that can withstand heavy use with relatively low maintenance (Scott 2018). The length and color of turf fibers has also been modified, such as integrating short, brown, nylon fibers resembling thatch into green turf to generate an even more realistic look for some 3G artificial turf products.

Fourth generation (4G) or higher artificial turf products are not recognized by sports authorities or “governed by any recognized standards” (Tiger-Turf 2018). They are typically of the same material and construction as 3G turf but have other types of infill.

It is important to note that these are general advancements in artificial turf technology; turf systems and material composition vary within generations depending on intended usage.

3.2 Description and variations of modern artificial turf

The two main components of artificial turf systems are the turf and the base. The turf system (Figure 3-1) is composed of the grass-like fiber or pile, infill material, and a backing. The base includes drainage networks and foundational stones and sediment.

Figure 3-1. Third-generation artificial turf “soil profile.”

Source: Wilson and Boehland 2018.

Artificial turf is used for a variety of purposes, such as playgrounds, athletic fields, pet relief areas, and residential lawns. Products and system design vary depending on its application. The intended use of an artificial turf installation dictates the pile or fiber material, pile length, infill material, and drainage system design. Note that sports authorities recognize other variations of quality, which are not discussed in this report. These include modifications to system design as well as quality inspections and maintenance standards for the health and safety of athletes. Appendix B includes a list of the material composition of select artificial turf systems.

3.2.1 Pile material

Most artificial turf fiber is made up of one or a mix of three materials: nylon, polypropylene, and polyethylene. Choice of material(s) determines durability, flexibility, optimal uses, and aesthetics of a field.

3.2.1.1 Nylon

Fibers made of nylon are thick, curled and closely compacted to the surface. Nylon provides the sturdiest and most stiff pile material, which can withstand heavy usage while still maintaining its shape. It also performs well against high temperatures. Because nylon fibers are permeable, they can easily absorb and retain water (EasyTurf 2010, Home Stratosphere 2018). This, along with its characteristic rigidity and flatness, make it highly preferred by field hockey applications, where the saturation of the field allows for better maneuverability of the ball.* However, this same permeability makes it susceptible to absorbing odors. Because of its rigidity and abrasiveness, use is typically limited to a few sport applications, or as thatch in combination with softer polyethylene fibers to mimic the aesthetics of dead thatch in natural turf (Scott 2018, SGW 2013). Nylon is the most expensive of pile fiber materials (Home Stratosphere 2018).

3.2.1.2 Polypropylene

Polypropylene pile is longer, thinner, and softer in texture than nylon pile. Its feel and look more closely resembles natural turf. However, it is the least durable fiber material against heavy usage and high temperatures, which lead to disfigurations in fiber shape. Optimal applications include indoor

* Personal communication between Amanda T. Rodriguez, ERDC-CERL, and Jonathan Huard, FieldTurf Regional Sales Manager. 18 October 2018, cited hereafter as 'Huard 2018'.

golf putting, other indoor uses, and decorative purposes (Scott 2018). This is the least expensive form of artificial turf (Home Stratosphere 2018).

3.2.1.3 Polyethylene

Polyethylene pile material most closely resembles the feel, look, and durability of natural turf; it is the most commonly used fiber material in artificial turf systems. Fibers made of polyethylene are like polypropylene but are softer in texture. This soft texture prevents “turf burns” and abrasions that occur more characteristically with nylon pile. Polyethylene fibers are also much more durable than nylon fibers. Polyethylene pile is also more resistant to ultraviolet (UV) degradation than nylon pile. When mixed with nylon, polyethylene fibers maintain their shape longer, though combining the two is not always recommended since each material wears differently and requires different maintenance regimes (EasyTurf 2010, Scott 2018, Huard 2018). Polyethylene is non-porous, so it does not absorb and retain odors and can easily drain waste and bacteria rinsed with water, making it ideal for pet relief and athletic use (Home Stratosphere 2018). Cost of turf systems made of polyethylene varies greatly. The quality (and corresponding price) of polyethylene turf typically dictates its sturdiness and ability to withstand usage without flattening (Home Stratosphere 2018).

3.2.2 Pile height

Pile height is the length of the turf blade measured from the tip to its attachment to the backing, which determines the amount of infill that can be used, and therefore the relative cushion a field provides (Huard 2018). This influences the optimal usage, relative safety, and aesthetics of the field.

Pile height is especially important in athletic applications. Most fields, e.g., those for soccer, lacrosse, field hockey, softball, and baseball, have a 2-in. pile, a 1¼-in. infill, and ¾ in. of exposed blades. Fields for high contact and tackling sports, such as football and rugby, require 2¼ to 2½ in. in pile height, i.e., 1½ to 1¾ in. infill and ¾ in. of exposed blades. For multi-purpose fields, pile height is typically determined on a case-by-case basis, considering the primary activities of the field (Huard 2018). In contrast, height can act as barrier to peak performance for “roll sports,” increasing the amount of friction between the turf and the ball. This is especially true for golf, where minimal resistance is preferable and pile height is short.

Pile height also impacts aesthetics of a field: the shorter the height, the less natural or lush the turf appears. However, the longer the pile, the more likely it is to not support its own weight and to more easily flatten over time (Home Stratosphere 2018).

3.2.3 Infill material

On artificial turf fields, infill refers to the granules in between the blade fibers that give the fibers support to stand upright (Huard 2018). Infill provides cushion for athletes on impact and protects the turf backing from excessive wear and rips (Huard 2018). Types of infill include crumb rubber (both recycled and virgin), sand, fine-grain mulch (e.g., cork, coconut peat), recycled post-consumer products, and modified or coated variations of these materials (FieldTurf 2018). They can be applied, in layers, in combination with each other. Choice of infill material depends on the purpose of the field, the type of pile, regional climate considerations, and personal preference.

Crumb rubber is the most commonly used infill material for athletic applications because it cushions and absorbs athlete impact and because its loose compaction minimizes joint injuries (Williams 2010). Although crumb rubber is typically (though not exclusively) sourced from used tires, it can also be made from variations of virgin rubber such as thermoplastic elastomers (Watterson 2017).

The choice of infill can function as a temperature-regulating feature, although there is some disagreement regarding the degree of effectiveness. Modifications and coatings can be added to crumb rubber or other infill material to increase its water absorbency and retention, which enhance the temperature-regulating effect of water that would otherwise drain quickly.

Nylon-fiber field hockey sports fields are the only applications where infill is optional (Huard 2018). The turf is irrigated prior to games and general usage of the field. The water acts as an “infill” on the field because nylon fibers retain water so well (Huard 2018).

3.2.4 Base and drainage system

Base design is not unique to artificial turf fields; it is implemented on natural and artificial fields alike to optimize long-term structural stability, levelness, drainage, and stormwater management and flow. However, major variations in base design are typically for the purpose of drainage and

stormwater management. Turf backing, base stones and sediments, drainage pipes, and the field grade or slope are all components that can be modified to influence the drainage potential of a field (Figure 3-2).

Figure 3-2. Cross-section representation of typical field drainage system.

Source: Hebert et al. 2017

Quick drainage to minimize standing water on a field allows artificial turf fields to be functional during and after rain events or irrigation. This functions as a major selling point for artificial turf technology. However, there are reasons to limit drainage potential of fields. First, it can be expensive to fully optimize quick and complete drainage of most or all water off a field. To minimize costs while still effectively draining fields for usage, drainage design schemes that are in line with the regional frequency and intensity of rain events are recommended.

Artificial turf fields can be irrigated to regulate high surface temperatures because artificial turf easily absorbs heat, which can limit usage of the field. If water is quickly and completely drained off a field, this will reduce the regulating effect of watering and temperatures will quickly rise to pre-irrigated levels. For installations that experience high temperatures and plan on irrigating fields to regulate surface temperature, systems will need to be designed to balance drainage and water retention for this purpose. Fiber, backing, and, in some cases, crumb rubber (which can be manufactured to increase water absorption) can impact the retention of water for this purpose.

Lastly, certain sport-specific fields, such as field hockey turf, require a certain amount of water in the fiber and infill for optimal playing conditions.

These fields will require drainage systems that do not quickly drain water (Hebert 2017).

For more information on drainage components and site considerations, see the *Guidelines for Synthetic Turf Base Systems* (Hebert et al. 2017) for specific drainage components and design considerations.

3.2.4.1 Drainage design

Fields are slightly sloped to facilitate quick drainage of water off the fields. As water flows down the slope of the field, it is captured by the lateral trenches and is siphoned off to sideline trenches that border the field (see Figure 3-3) (J-Drain® SWD 2016). Drainage design can be altered depending on the outlet of drainage, e.g., whether the water can percolate into groundwater or is siphoned to a stormwater conveyance.

Figure 3-3. Drainage scheme with sideline trenches and lateral drains.

Source: J-Drain® SWD 2016.

3.3 Life-cycle requirements

Requirements throughout the installation, maintenance, and disposal of a field will vary by state or municipality, anticipated and actual usage, site landscape, and regional climate considerations and limitations. This section lists the general requirements found in the literature review.

3.3.1 Installation

The installation of an artificial turf field first requires evaluations of the conditions and characteristics of a site's soils and hydrology. Plans can then be developed and implemented based on the results of these evaluations. Improper development of the foundation and drainage of the field can cause conditions that result in a need to unstitch the carpet and dig up some or all components of the base to correct the base. Table 3-1 lists the general steps or requirements during the installation process.

Table 3-1. List of requirements during the installation process.

Requirement	Summary
Storm Water Runoff Analysis (42 USC 17094)	"Maintain or restore ... the predevelopment hydrology of the property with regard to temperature, rate, volume, and duration of flow."
Geotechnical Soil Report	Identify soil composition, potential for settlement and expansion, supporting capacity and drainage characteristics (Miller Pacific Engineering Group Undated).
Base Excavation, Grading, and Shaping	Excavation of soils and the grading of field.
Lime Stabilization	Depending on the soil characteristics, lime stabilization can improve long-term stability.
Cement Treatment	Mixture of native soils and cement mixture, providing a supportive base.
Drainage Pipes and other Infrastructure	Installation of drainage components.
Stone Base and Soil	Infill base with stones and soils.
Shock Test	Test of impact absorption (not required on an average field).
Carpet	Lay and stitch turf carpet.
Turf Infill	Deposit infill material.
Combing Pile Fiber	To make upright and separate from each other.

3.3.2 Maintenance

The wear, aesthetics, and safety of an artificial turf field depends both on usage and maintenance. The frequency and components of field maintenance should correspond with the type of field (whether it is located indoors or outdoors) and to its level of usage. Manufacturers or installers will conduct quarterly or bi-annual inspections for rips, tears, and compaction, depending on the warranty associated with a field. Most routine maintenance, such as vacuuming, magnetic sweeps, UV disinfecting, and repairing minor rips and tears, are done by onsite landscape management personnel. Table 3-2 lists potential components of proper artificial field maintenance.

Table 3-2. Potential components of field maintenance.

Maintenance	Summary
Vacuum	Vacuum collects debris, sorts out crumb rubber, redeposits crumb on field
Magnetic sweep	Magnetic sweeper collects nails and cleat spikes that pose a health hazard for athletes
UV disinfectant	Disinfects fields against bacteria build-up from biofluids; particularly important for indoor fields
Irrigation or rinsing of field	For the purpose of regulating temperatures, field aesthetics, infill, or rinsing away biofluids or spills
Deep clean grooming	Cleans and brushes blades to stand upright, cleans crumb rubber
Shock/compaction test	Tests impact absorption; typically done on a yearly basis
Crumb rubber replenishment	Typically done on an as-needed basis or every 1-2 years
Repairing rips/replacing patches	Repairs and replacement are typically done for portions under heavy use; done on an as-need basis
Drainage failures	Requires unstitching some or all portions of the carpet and the base soils to access and fix the drainage

3.3.3 Disposal and resurfacing

Once an artificial turf field has reached the end of its life span, it must be unstitched or ripped up and properly disposed or recycled. Fields can either be resurfaced with new artificial turf or returned to natural turf.

3.4 Warranties and life expectancy

Field warranties, which can be purchased for both residential and athletic applications, are a necessary component to artificial turf installations that provide a financial safety net after high investment costs. This is based on informal discussions with representatives from this report's case studies. A

field warranty typically lasts 8 to 10 years and protects buyers from assuming repair costs due to faulty material or improper installation. Warranties also tend to include routine inspections from installers or manufacturers for rips, tears, compaction, field levelness, and proper maintenance of the field, all of which help to ensure its longevity. However, warranties can also impose restrictions and conditions on buyers that limit the nature of field use. For example, a warranty might include a requirement that all field users wear cleats or other specific footwear, or that buyers perform specific maintenance regimes, or that heavy equipment be prohibited on the fields. Failure to adhere to warranty restrictions can void the warranty and its associated protections.

The life span of a field can vary depending on the type and quality of a product's material, the purpose of the application, the amount and type of use the field receives, and the routine and as-needed maintenance the field is given. Residential applications that are reasonably maintained have a life expectancy of 20 to 25 years (EasyTurf 2017, ProGreen Undated). The average life expectancy of an athletic field, based on this report's case studies, is 8 to 10 years. It is not uncommon for fields that experience heavy use to require replacement before the expiration of its warranty.

4 Human Health and Environmental Concerns

This chapter reviews adverse human health and environmental concerns that have been associated with artificial turf use, including heat risks, joint and concussion injuries, potential for bacterial infections, and chemical exposure.

4.1 Heat-island effect and heat-induced illnesses

Artificial turf systems have the potential to retain large quantities of heat, resulting in impacts like the heat-island effect. Artificial turf is generally 35 ° to 55 °F hotter than natural grass. Studies on new-generation artificial turf document a surface temperature high of 200 °F on a 98 °F day in Provo, UT (Williams and Pulley 2002) and 175 °F in central Pennsylvania (Penn State 2011). Similar studies in the past have illustrated the same effect. For instance, research on AstroTurf in the 1970s found surface temperatures up to 50 °F higher than natural grass (Buskirk et al. 1971, Koon et al. 1971, Kandelin et al. 1976). In comparison, surface temperatures of natural grass ranged from 75 °F to 95 °F and were lower than the air temperature.

High surface temperatures can affect field users by increasing heat transfer from field to user, greater chance of heat-related health effects, discomfort, dehydration, and heat stroke (Buskirk et al. 1971). While watering will reduce the surface temperature for a short period of time, temperatures rebound within 20 minutes of watering (McNitt et al. 2008). However, methods of alleviating the heat-island effect by irrigation counteracts the water efficiency of artificial turf grass.

Attempts to reduce surface temperature through different material compositions such as infill and fibers did not produce significant outcomes. Similarly, past attempts to water and then cover the field yielded few results. Consequently, it is recommended that use of fields be limited to mornings and evenings to mitigate exposure to higher temperatures that occur mid-day. Additionally, users should increase their monitoring of field temperatures and check for signs of user discomfort (Penn State Center for Sports Surface Research 2011).

4.2 Injuries

A concern related to the use of artificial turf as a playing surface is the perceived risk of increased rate and severity of injuries sustained when compared to natural grass playing fields, particularly concerning risk of joint and concussion injuries. However, while athletes playing on older generations of artificial turf (i.e., AstroTurf) did experience more injuries than those using natural grass, “the majority of injury studies involving infilled synthetic turf do not follow that same trend” (Serentsits 2012). Third-generation artificial turf is designed to “reduce friction, lower impact forces, and increase water drainage,” which can reduce cleat traction and rate of injury (Williams 2010).

In a study that followed 290 athletes from soccer clubs in Europe, “the total injury rate was similar when playing or training” on either natural grass or artificial turf fields (Williams 2010). In an examination of injuries for National Collegiate Athletic Association (NCAA) women and men’s soccer teams over two seasons (116 teams in 2005 and 126 teams 2006) using the NCAA Injury Surveillance System, researchers concluded that “there were no major differences in the incidence, severity, nature, or cause of match injuries sustained on new-generation artificial turf and grass by either male or female players” (Fuller et al. 2007). Existing literature supports the contention that risk of injury on artificial turf playing fields are comparable to risk of injury on natural grass fields.

4.2.1 Joint injuries

The risk of joint injury depending on the type of field relates to “biomechanical differences between cleat interactions” with the playing field, which can “result in stress to the ankle and knee joints” (Smith 2016, Williams 2010). The “sandpaper-like surface” of previous generations “tended to ‘grab’ the cleats of a player’s shoe and to not allow the cleats to ‘release’ as the player’s leg turned or rotated,” resulting in a high rotational traction that could cause serious injury to the ankle or knee (Serentsits 2012). The design of third-generation turf (long turf fibers and granular infill) “allows for easier ‘release’ of an athlete’s cleats from the surface of infilled synthetic turf, lessening the torque placed on the ankle and the knee” (Serentsits 2012).

In a study that analyzed 60 foot and ankle injuries over 3 years across four different sports for men and women (men’s football, women’s field hockey, and men and women’s lacrosse and soccer), the “frequency of total

foot/ankle injuries was no different between artificial turf and natural grass” and concluded that “field surface type [and age of artificial turf field] does not have an effect on foot/ankle injury frequency” (Smith 2016). However, this study examined injury frequency by number of players, rather than by number of hours trained, which would have provided a more appropriate comparison risk analysis.

4.2.2 Concussions

The likelihood of concussions due to impact with a field surface is related to a field’s impact attenuation capacity, or its ability to absorb and reduce the force of an impact experienced by a field user. Components of artificial turf systems, such as shock pads and the depth of crumb rubber, play a crucial part in determining attenuation impact capacity for these fields. As mentioned previously, fields for high contact and tackling sports, such as football and rugby, require longer pile height, which allows for an extra ¼ to ½ in. of crumb rubber infill and increases the attenuation impact capacity of these fields.

In terms of concussion risk due to head-to-surface contact, properly maintained artificial turf systems perform similarly to natural turf fields (Concussion Legacy Foundation 2015). In a study cited by Williams, while the Head Injury Criterion (HIC), an indicator of potential injury, for artificial turf and natural grass fields were below the standard threshold for injury, the impact attenuation capacity for third-generation artificial fields was greater than the capacity recorded for grass fields. Yet in colder temperatures, natural grass fields exhibited HIC levels more than 2.5 times greater than the threshold for injury, in contrast to a low HIC for artificial turf fields under the same conditions (Williams 2010). However, crumb rubber on artificial fields can be significantly compacted in sections of high and frequent usage, also diminishing impact attenuation for those areas (Concussion Legacy Foundation 2015).

Risk of concussion from contact with the playing surface varies by sport and age for both natural and artificial turf, heightened in high contact sports and in children (Concussion Legacy Foundation 2015). The expected activities and age of field users should influence design decisions to facilitate risk reduction. Turf systems should also be tested on an annual basis for compaction to mitigate the risk of concussion.

4.2.3 Turf burn abrasions

Athletes can develop dermal abrasions and cuts through friction abrasions with artificial turf. Abrasions and cuts in the skin provide an opening for bacterial infections, such as staph, prevalent in athletic facilities and work-out equipment. However, “turf burn” injuries sustained from artificial turf is similar in the rate and severity to abrasions developed from natural grass (Mount Sinai 2011).

4.3 Bacterial infections

There is considerable concern that artificial turf surfaces can lead to increased exposure and risk to bacterial infections, and are a hospitable breeding ground for bacteria, particularly staph. MRSA (Methicillin-resistant *Staphylococcus intermedius*) infections can occur when staph bacteria come in contact with open sores and cuts. As discussed in section 4.2.3, the likelihood of cuts and abrasions from contact with the field surface is not any higher for artificial turf than for natural grass fields.

While high surface temperatures pose a potential health risk to players, the high surface temperatures of artificial turf also aid in killing bacteria on the field. Researchers from Pennsylvania State University’s Center for Sports Surface Research examined the survival of staph bacteria over time. Three hours after introduction onto an outdoor, infilled synthetic field, almost all bacteria were dead. This was attributed to higher surface temperatures and exposure to UV light. Researchers found that the staph bacteria tended to have higher rates of survival on Kentucky bluegrass than on artificial turf. On indoor applications, “the staph bacteria survived for several days,” although this can be reduced to survival periods of less than 24 hours with the use of anti-microbial sprays and UV grooming machines (Serentsits 2012).

In a second study on the presence of staph bacteria on athletic gear and other surfaces, researchers identified staph bacteria on blocking pads, weight equipment, used towels and a stretch table. Researchers concluded that athlete exposure and risk to staph bacteria occurs through other mediums and is not uniquely contrived from artificial turf (Serentsits 2012).

According to the State of New York Department of Health, whether or not artificial turf fields contribute to more staph infections than do natural

grass fields, they conclude that the issue “has not been systematically studied, and no definitive statement can be made about differences in risk between the two surfaces” (NYSDOH 2008).

4.4 Chemical composition and exposure

The use of crumb rubber, particularly strains manufactured from recycled tires, is the primary driver for concerns over chemical exposure and associated health and environmental risks. Appendix B provides a description of the general chemical make-up of artificial turf pile, infill, and backing of various brands and products.

4.4.1 Human health concerns

Several chemicals that can be found in crumb rubber (Table 4-1)) are known or suspected carcinogens, neurotoxins, and potential endocrine disruptors (Watterson 2017). Nevertheless, the presence of such chemicals alone does not indicate a real risk or health implications. A true evaluation of chemical exposure risk considers (1) concentration and quantity of a chemical, (2) method of exposure (via off-gas inhalation, dermal or ocular absorption, or direct or indirect ingestion), (3) length of exposure, (4) toxicity or strength of a chemical, and (5) field user age (Johns 2008, Mount Sinai 2011).

In a study done by the City of New York, researchers found that “while low levels of contaminants were occasionally present, in most cases, the levels were no different from ‘background’ levels” on control areas away from artificial field test sites. This corroborates results from many studies that concluded that chemical concentrations in crumb rubber were below levels deemed harmful to human health (Serentsits 2012).

Table 4-1. Types of chemicals found in recycled crumb rubber leachate.

Chemical Class	Example Chemicals	Other Ways Humans May Be Exposed
Metals	arsenic, cadmium, zinc, copper, lead, iron	varies by chemical, but may include consumption of contaminated foods, water contamination due to rusting pipes, automobile exhaust
Phthalates	Bis (2-ethylhexyl) phthalate	household cleaning products, plastics
Polyaromatic hydrocarbons (PAHs)	benzo(a)pyrene, pyrene	breathing air contaminated with smoke or exhaust, eating charred meats (e.g., hamburgers)
Polychlorinated biphenyls (PCBs)	various congeners and aroclors	consumption of contaminated food, electrical appliances
Volatile organic compounds (VOCs)	benzene, toluene	freshly paint, rubber-based floors, auto exhaust
Source: Johns 2008		

However, in an extensive review and discussion on recycled crumb rubber studies, Andrew Watterson of the University of Stirling in Scotland points out that because “the technology and materials used [on artificial turf fields] are evolving globally, ... it can be difficult to assess their specific or combined health effects, if any, or identify exactly what crumb rubber material and what quantities and from what source have been or are used now in the original installations in very varied locations and climates and with what chemical and metal concentrations” (Watterson 2017). Additionally, compared to the rigorous and numerous studies done on joint injuries, studies done on chemical release and exposure are fewer in number and have methodology limitations, such as the basing of conclusions on theoretical rather than experimental exposure levels (Watterson 2017). Tables 4-2 and 4-3 summarize key crumb rubber chemical exposure studies, their strengths and weaknesses, and results.

Currently, two comprehensive studies are in progress that aim to fill knowledge gaps and establish more conclusive evidence on chemical exposure from crumb rubber and artificial turf systems. The first is a federal multi-agency investigation led by the U.S. Environmental Protection Agency (USEPA). Also participating are the Center for Disease Control (CDC)/Agency for Toxic Substances and Disease Registry (ATSDR) and the Consumer Product Safety Commission (CPSC). In 2016 the agencies launched the *Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds*, which examined potential environmental and human health impacts from recycled crumb rubber.* The study’s objectives were to fill data and knowledge gaps on the content of crumb rubber and the methods and degree of exposure based on activity type via lab and field experiments. The crumb rubber characterization portion analyzed samples from nine tire crumb manufacturing or recycling plants and a combination of 40 indoor and outdoor fields. Note: the final, peer-reviewed report has not been released at the time of this publication.

The second study, led by the California Environmental Protection Agency’s (CalEPA) Office of Environmental Health Hazard Assessment (OEHHA), focused on potential human health impacts of both artificial turf carpet and crumb rubber. Objectives of this study were to determine crumb rubber composition and off-gassing levels, develop exposure scenarios, and

* A more detailed description of this ongoing effort, including a link to an abstract in Portable Document Format (PDF) format may be found through Universal Resource Locator (URL):
https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=342319&Lab=NERL

conduct preliminary field studies on exposure scenarios and levels on playgrounds (OEHHA 2018).

Although characteristic of many literature reviews on the subject, the aforementioned concerns regarding existing literature (as well as limitations presented in Tables 4-2 and 4-3) suggest that it may not be appropriate to make generalizations about the real health implications of crumb rubber use based on conclusions from a small sample of case studies. We defer conclusions on the chemical safety of crumb rubber to those made in the *Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds* and the OEHHA study.

Table 4-2. Summaries of key studies suggesting low potential risks from crumb rubber.

Subject	Type of Study, Methods, Size, Strengths, and Weaknesses	Reference	Results
Environmental and health assessment of the use of elastomer granulates (virgin and from used tires) as filling in third-generation artificial pitches.	Lab-based using scenarios including looking at one pitch monitored over 11 months period and analyzing VOC and metals including impacts on the wider environment and an evaluation of health risks from gas emissions. Total VOC for artificial turf was $8.3 \mu\text{g}/\text{m}^3$ at 28 days. Relatively small study but one of the few to address risks to workers installing surfaces.	Moretto 2007	VOCs and formaldehyde were either very or relatively low with levels highest and were not considered a health threat to sports people and spectators from crumb rubber. Largest risk was to workers laying turf over a 5 years period in small and poorly ventilated buildings.
Hydroxypyrene in urine football players after playing on artificial sports field with tire crumb infill.	Studied seven non-smoking players aged 21 or more exposed for 2.5 h over 3 days period with intensive contact with crumb rubber. Lab-based plus only widely cited human biomonitoring study of crumb rubber chemicals. Very small study in scope and length, and partly funded by industry. Controls for doses from other sources that may accumulate with crumb rubber chemicals.	Van Rooij and Jongeneelen 2010	The researchers found no or minimal exposure to certain chemicals from urine samples and within range of uptake from environmental sources and/or diet. The total PAH of the pitch crumb rubber concentration was 24 mg/kg.
Crumb Rubber Infilled Synthetic Turf Athletic Fields. New York.	U.S. study using artificial bio fluids looked at eight artificial fibers, eight infills and samples from seven fields.	NYSDOH 2008	Chemical exposures often below detection levels and metals at levels of "low" estimated human risks with the possible exception of lead.
Human Health Risk Assessment of Artificial Turf in Connecticut.	Air sampling from one indoor pitch with no active ventilation and four outdoor pitches in summer conditions. Testing for chemicals. Small study, limited range and researchers considered benzene levels recorded above background levels could have been due to personal sampling equipment problems. Ingestion potential not part of study.	Ginsberg and Toal 2010	27 chemicals of concern at above background levels found and possibly field related in all four locations, but the study concluded none were associated with elevated health risks. Benzothiazole on one pitch recorded at $6.5 \mu\text{g}/\text{m}^3$ on surface.

Subject	Type of Study, Methods, Size, Strengths, and Weaknesses	Reference	Results
Artificial turf pitches—an assessment of health risks for football players. Oslo, Norway.	Exposure study based on three halls with granulates laid at different times and of different materials. Small study using scenarios of limited range. Study informed later inhalation and oral exposure studies.	Bjørge 2006	Estimated that health risks were low VOC exposure inhalation Adults = 0.32 m ³ /kg body wt/day Juniors = 0.16 m ³ /kg body wt/day.
An assessment of health risks for football players and the environment. National Institute of Public Health, Norway.	Based on three reports. Weaknesses were that data on oral rubber intake were lacking, many VOCs monitored were not classified so health risks were unknown, many VOCs only had acute and not chronic effect classifications. It did note “artificial turf that contains substances of very high concern should not be used.”	Bjørge 2006	Estimated that health risks were low. Children may swallow some rubber granulate (1.0 g) during matches and/or training sessions Worst case inhalation measurements in Manglerudhallen (recycled rubber granulates), 234 different chemicals were found. This gave a total VOC of approximately 716 µg/m ³ (indoor house VOC of 200 µg/m ³).
Measurement of air pollution in indoor artificial turf halls.	Measurements taken in a hall with recently laid rubber granulate (SBR), a hall with rubber granulate (SBR) that had been in use for 1 year and a hall with granulate made from thermoplastic elastomer. Noted gaps in literature on materials, some compounds not identified and some not studied.	Dye et al. 2005	Found low levels of many chemicals but noted “due to the dimensions of a football pitch, inadequate product research before launching a product will lead to a risk of undesirable exposure to chemicals with adverse health effects.”
Evaluation of health risks of playing sports on synthetic turf pitches with rubber granulate.	Literature review and analysis of rubber granulate from 100 Dutch pitches. 720 samples taken from six positions on each pitch. Limited number of migration tests used. Used artificial sweat and assessed migration of chemicals. Developed exposure scenarios for children including goalkeepers and adults. Recognition that the chemical exposures recorded in the study met general European limits for mixtures but would not meet the toy and consumer limit exposure limits. Assumes epidemiological studies reviewed can assess cancer risk but this is contested.	RIVM 2017	“Health risk of playing sports on synthetic turf pitches with an infill of rubber granulate is virtually negligible.” Maximum pitch concentration found for Benzo(a)pyrene (BaP) was 2.2 mg/kg dry matter noted two earlier studies in Europe reported higher concentration of BaP than theirs with maximum values of 8.58 and 11 mg/kg. Low level of toluene, xylene, and styrene detected but no benzene.
Source: Watterson 2017			

Table 4-3. Summaries of key studies suggesting potential risks from crumb rubber.

Subject	Type of Study/Methods/Size/Strengths and Weaknesses	Reference	Results
Contents of metals and chemicals in artificial turf. Lab-based and exposure study.	Recycled rubber granulate content from 13 Italian fields. Analysis of 25 metals, nine PAHs. Air samples from two fields. Small sample size and lack of actual exposure scenarios issues.	Menichini et al. 2011	BaP and zinc levels in granulate exceeded Italian “green” soil standards by two orders of magnitude. Worst case excess cancer risk assessment of BaP in air was 1×10^{-6} , over 30 years at 0.4 ng/m ³ .
Hazardous organic chemicals in rubber recycled tire playgrounds and pavers. Lab-based.	21 rubber mulch samples collected from nine different urban playgrounds and seven commercial paver samples from a store. Analysis done for 31 PAHs, phthalates, and antioxidants, and of vapor phase above samples. Relatively small sample size, other sources of chemicals question raised.	Llompert et al. 2013	High levels of several toxic chemicals found in the recycled materials especially BaP found in five samples. PAHs in commercial pavers was “extremely high,” up to 1%.
PAHs, heavy metals release from rubber crumb in synthetic turf fields. Lab-based.	Lab analysis of nine football pitch samples of rubber crumb normally found in tires and their metals and PAHs. Risk assessment at 25 °C was done. Study preliminary and relatively small and acknowledges risk assessment over-estimates PAH contribution from fields.	Marsili et al. 2015	Toxic equivalent of evaporates from crumb rubber “not negligible” and represented major part of total daily PAH intake by different routes. Noted “continuous release” of PAHs from evaporation and issue of chronic exposure.
Threshold levels for carcinogens and policy implications of the National Institute for Occupational Safety and Health (NIOSH) analysis.	Review of chemical carcinogens policy. Looks at classification risk management limits and advocacy of a policy of elimination or substitution and implementation of engineering controls. Limitations include its purpose is to consider worker exposure although exposures to carcinogens do not differentiate between worker, consumer, and citizen and the precautionary principle applies across the board.	NIOSH 2017	“Underlying this policy is the recognition that there is no known safe level of exposure to a carcinogen and therefore that reduction of worker exposure to chemical carcinogens as much as possible through elimination or substitution and engineering controls is the primary way to prevent occupational cancer.”
Source: Watterson 2017.			

4.4.2 Environmental concerns

Recycled crumb rubber contains various chemical vulcanizers, oil-based plasticizers, antioxidants, antizoonants, and fillers (Cheng et al. 2014). As discussed with human health concerns, the presence of hazardous chemicals is not necessarily indicative of certain environmental repercussions. In addition to factors such as chemical concentration, toxicity, and method

of release (i.e., off-gassing, leaching, etc.), chemical environmental risk assessments should consider chemical leaching potentials and bioavailability, or the degree or method in which chemicals are absorbed by humans and other organisms. Determining leachate potential requires an understanding of the conditions under which chemicals are released and the types and concentrations of those chemicals released (Johns 2008, Johns and Goodlin 2008).

Leachate tests use various methods to determine the types and concentrations of chemicals that can be extracted from crumb rubber; however not all these tests mirror conditions that might occur in the natural environment. Only a few of the chemicals identified as components of crumb rubber resulted in leaching under experiments that better represent natural conditions (Johns and Goodlin 2008).

In a study published in 2004 by Plessner and Lund on four types of recycled crumb rubber and one type of ethylene propylene diene monomer (EPDM) crumb rubber, less than 0.001% of the total concentration of crumb samples' chemicals was released as leachate. The only exception was zinc, which released between 0.01 to 0.31% across the samples (Johns and Goodlin 2008). This is the trend for other studies' results as well: potentially hazardous metals and organic pollutants are found to leach from crumb rubber samples at levels typically below regulation standards, however zinc leachate levels are elevated (Cheng et al. 2014). While zinc at high concentrations can be toxic or harmful to aquatic life, ecological risk can be reduced by dilution of concentrations from precipitation and groundwater recharge (Cheng et al. 2014).

Crumb rubber sourced from used tires has been found to release more toxic leachate than non-recycled crumb. This can be attributed to the relative degradation of the tire crumb, facilitating easier and greater release of chemicals.

However, there are similar limitations in the strength of conclusions that can be made from these studies, namely that the number of studies is relatively small and the predominance of lab rather than field experiments in determining leaching chemicals and concentrations.

4.5 Environmental footprint

Artificial turf has received attention for its ability to reduce or eliminate the demand for water, pesticides, herbicides, and fertilizers, and its contribution

to the reduction in the number of used tires sent to landfills by repurposing them instead. Figure 4-1 illustrates the life-cycle environmental impacts of three artificial turf systems compared with a natural turf field. Impact levels were based on 300 and 600 hours of annual use availability for the natural grass and the artificial turf fields, respectively (Cheng et al. 2014).

Figure 4-1. Comparison of life-cycle environmental impacts.

Source: Cheng, Hu, and Reinhard 2014.

5 Life-Cycle Cost Analysis

LCCA is a tool that considers all costs and benefits accrued during the life of a technology, its initial purchase price, its operations and maintenance costs, and the cost to dispose at the end of life. LCCAs are mandatory for Military Construction Army (MCA) projects and for the application of special project funding categories such as the Energy Resilience and Conservation Investment Program (ERCIP), which may rank projects based on parameters such as savings-to-investment ratio or payback. The willingness of a contractor to participate in an Energy Savings Performance Contract (ESPC) project will also hinge on the economics of that project, that is, whether the contractor's investment will be "earned back" through annual cost savings.

Army installations are subject to the Tri-Services Memorandum of Agreement (MOA) relating to LCCAs for energy and non-energy projects, which are consistent with the Federal Energy Management Program (FEMP) and the Office of Management and Budget (OMB) (1991). These standards establish utility escalation rates and annual discount factors annually that enable projects to be evaluated and compared on equal footing (OMB 2015). They also offer guidance in the preparation of LCCAs that includes software tools (NIST 1995). National Institute of Standards and Technology (NIST) guidance allows incorporation of non-monetary benefits such as aesthetics, historic preservation, security, and safety.

5.1 Cost comparison to natural turf

Few unbiased comparisons of the costs of artificial versus natural turf fields exist. Even so, life-cycle costs can vary widely depending on several factors, though the principle consideration for the cost of artificial turf fields is the size of the field and the type of play. Other factors include drainage and irrigation systems, soil, climate, and prevailing labor rates. These factors will affect the cost of surface preparation, which includes excavation, new foundation material, and compacting the foundation. The variables of turf components include quality of fibers, padding, backing, and infill. Specific elements of artificial turf include edge material, type of attachment along edges, turf density, type of backing, sewed or glued lines and seams, type and quality of infill, and intricacy of logos and end-zone lettering, borders, and other inlaid markings. Installed cost estimates of artificial turf include all material and labor costs and range from \$6 to \$11.76/sq ft (Simon 2010, STMA 2008).

Costs for natural turf fields also varies widely depending primarily on properties of the land. These include soil type (whether additives are needed to support propagation of turf) and whether drainage is required (and if it is, and the appropriate type to install, e.g., sand cap and drainage). Specific items that may affect the cost of natural turfgrass fields include topsoil, type of turfgrass cultivar, sod versus sprigs versus seed, sod thickness, seed mixture and seeding rate, sod accessibility, and soil interface issues. Costs will vary between the following configurations: natural with native soils, natural with onsite native soil, natural with sand and drainage, and natural with sand cap. Table 5-1 lists typical costs for installing a natural turf field (Simon 2010, STMA 2008).

Table 5-1. Typical range of costs for a natural turf field (85k sq ft grass field).

Natural Field Type	Cost
Seed	\$102,000
Sod	\$191,250 - \$446,250
Basic Sand	\$250,000 - \$350,000
High-End Sand	\$722,500
Source: Simon 2010	

Installation costs that are common to both types of fields may include Architect and Engineer (A&E) costs, environmental impact, excavation/site prep, permits, bonds and insurance, engineering and as-builts, rootzone and drainage materials, erosion and sediment control, storm drainage system, and peripherals such as light towers, bleachers, sidewalks, and fencing (STMA 2008) (Table 5-2).

Case studies that compare installed costs show a range. Berkeley's calculations resulted in artificial turf installation costs of from 0.7 to 9.8 times more than natural turfgrass installation. This review produced a mean value of \$8.88/sq ft of artificial turf and \$4.24/sq ft of natural turf (Simon 2010).

Table 5-2. Estimated installation costs for artificial and natural turf fields.

Resource	Context of Research	Synthetic	Natural	Number of Times Greater Cost of Synthetic Turf Installation as Compared to Natural Turf
Turfgrass Resource Center (2008)	A publication that addresses concerns about synthetic turf using scientifically backed data for a non-profit trade association that represents the turfgrass sod industry.	\$850,000 – \$1,000,000	\$50,000 – \$600,000	1.4 to 20
Williams and Pulley (2002)	An investigation conducted at Brigham Young University (BYU) for their football field, of which half is synthetic and the other half is sand-based natural field.	n/a	n/a	11.8
Powell (2005)	A conference presentation aimed at athletic field managers addressing the complexities of natural and synthetic turf. Powell is a turfgrass agronomist with the University of Kentucky.	Basic: \$600,000 High-End: \$1,000,000	Soil: \$50,000 Sand: \$1,000,000	0.9 to 18:1
Claudio (2008)	A journal article in Environmental Health Perspectives (EHP), a monthly peer-reviewed research and news publication by the U.S. National Institute of Environmental Health Sciences, National Institutes of Health, Department of Health and Human Services.	\$1,400,000	\$690,000	2.0
Skindrud (2005)	A case study for an installation at Springfield College in Springfield, Massachusetts, in an informational article comparing natural and synthetic fields for landscape contractors.	\$800,000	\$400,000	2
Source: Simon 2010.				

In addition to installed cost, lifetime operations and maintenance costs of each field type must be considered. Table 5-3 lists equipment and suggested costs, not including removal and disposal of artificial turf at end of life. Some of the required equipment is common to both types of turf. Maintenance intervals will vary both between turf types and depending on the usage and the location of the field (indoors/outdoors and geographic region). Fields located in regions that receive regular rainfall may require less water washing. Factors that affect maintenance are amount of use and level of play, multi-sport use, weather and climate, soil and terrain, water availability and irrigation system, budget (including personnel availability), owner's goals, type and quality of field construction, and field security (protection against vandalism, non-regulated play, etc.) (STMA 2008)

Table 5-3. Summary of required equipment and suggested costs based on field type.

Equipment	Artificial	Natural
Tractor/utility cart	\$7,000 to \$16,000 (a) \$2,500 to \$16,000 (b)	\$7,000 to \$18,500 (a)
Assorted hand tools	No cost estimate given	No cost estimate given
Sweepers/blowers	\$1,500 to 20,000 (a) \$1,500 (c) \$1,500 to \$20,000 (b)	No cost estimate given
Broom, brush or tine	\$500-3,000 (a) \$500 (c) \$500 to \$3,000 (b)	
Roller	\$250 to \$2,000 (a) \$250 to \$2,000 (b)	
Mower		\$13,000 to \$69,000 (a) \$107 (d)*
Spraying equipment	\$1,000 to \$35,000 (a) \$1,000 to \$35,000 (c)	No cost estimate given
Aerator		\$3,500 to 17,000 (a)
References: (a) Turfgrass Resource Center (2008) (b) Synthetic Turf Maintenance EquipmentII (Brakeman 2005) (c) 2004-2005 Maintenance Budget Synthetic Infill FieldII (Brakeman 2005) (d) New Yorkers for Parks (2006)		
*yearly cost for a 5-year lifetime		
Source: Simon 2010.		

Maintenance costs specific to artificial turf include sweeping, dragging, fluffing, redistributing, and shock testing of infill; periodic disinfection of the materials; topdressing of sand-rubber; seam repairs and infill replacement; and watering to lower temperatures on hot days, troubleshooting minor repairs, and snow removal. Maintenance costs are higher for multi-use fields and for those that are highly visible (STMA 2008). Costs for removal of artificial turf at end of life are estimated at \$3/sq ft, which includes returning the site to natural turf (Uhlman et al. 2010, TURI 2016).

Costs specific to natural turfgrass fields include expenses related to the maintenance of a living ecosystem, i.e., mowing, watering, fertilizing, addressing disease and pests, and replacing sod. Natural fields may need recovery time from environmental stressors or overuse. Organic turf maintenance has been shown to cost 25% less than a conventional turf management program (TURI 2016).

Summary of the total cost of ownership was calculated over a 10-year time frame. These costs assume that both types of turf will last for 10 years. The data in Table 5-4 may be used to compare two types of natural and artificial turf fields, annualized for a 16-year scenario. The data in Table 5-5, which list costs related to artificial turf and sod for a 78,000 sq ft field in a private stadium, normalize the cost of ownership to a cost per use. This is usually the finding by artificial turf industry estimates.

Table 5-4. Annualized costs for natural and artificial turf, 16-year scenario.

Field type	16-year annualized costs
Natural soil-based field	\$33,522
Sand cap grass field	\$49,318
Basic synthetic field	\$65,849
Premium synthetic field	\$109,013
Source: Brad Fresenburg, "More Answers to Questions about Synthetic Fields – Safety and Cost Comparison." University of Missouri.	

Table 5-5. Cost per use for sod and artificial turf, annualized for a 10-year scenario.

Type of Cost	Artificial Turf	Sod
Installation cost	\$692,640	\$330,720
Year 1 costs	\$14,900	\$65,258
Year 2 costs	\$14,900	\$65,258
Year 3 costs	\$14,900	\$65,258
Year 4 costs	\$14,900	\$65,258
Year 5 costs	\$14,900	\$65,258

Type of Cost	Artificial Turf	Sod
Year 6 costs	\$14,900	\$65,258
Year 7 costs	\$14,900	\$65,258
Year 8 costs	\$14,900	\$65,258
Year 9 costs	\$14,900	\$65,258
Year 10 costs	\$14,900	\$65,258
10-Year life-cycle cost	\$841,640	\$983,300
Uses during 10-year cycle	1,400	350
Cost per use	\$601.17	\$2,809.43
Key Assumptions: Artificial turf cost of \$8.88 per sq ft, \$4.24 for natural turf (sod) Includes general maintenance, equipment, and water costs (annualized average amounts) Assumes field does not already consist of natural grass Does not include "replacement" costs, which may or may not occur during mid-point of life of installation		
Source: Simon 2010.		

The cost per event is based on assumptions such as 3,000 hrs./year of availability for artificial turf versus 816 hrs./year of availability for turfgrass fields (Act Global 2018). Questions that should be answered include, does an extension of hours include after daylight ends? What about additional energy for lighting at night? Even though fields are available for more hours, will they be used for more hours? Is there an equal demand for sports fields regardless of the time of day?

5.2 Considerations for conducting cost-benefit analysis

To achieve an accurate cost-benefit analysis, it is critical to consider the full life-cycle costs of an artificial turf system, including installation, maintenance, and disposal/replacement. Significant investments are required at each stage of the product life cycle. In general, costs for artificial turf are higher; however, non-monetary benefits may be realized such as increased access to the fields. This is a significant benefit where fields support military training requirements.

It is important to use project-specific data for the cost-benefit calculation, specifically, data that reflects increased access to an artificial turf field as compared to turf grass. The data in Table 5-6, which was provided by an artificial turf manufacturer, quantifies the minimum number of events that could take place on one artificial turf field, including 759 events in 12 categories. Some of these events could be expected to occur at the same time (football and soccer share seasons in high school sporting leagues).

Table 5-6. Annual minimum number of events to take place on an artificial turf field.

Activity	Number
Football Games	20
Intramural/PE Classes	160
Football Practice	90
Football Playoff	2
Playoff Football (Rental)	20
Band Practice	10
Lacrosse	50
Soccer Games (m/w)	45
Soccer Practice	200
Graduation	2
Misc. (Community Use)	100
Field Hockey	60
Total	759
Source: PolyTurf 2008.	

Given the high usage by high school activities, would there be enough availability of a field for 100 community events? Would the demand for non-school uses occur during times of availability? Another important consideration is warranty exclusions. Complying with all restrictions may reduce the availability of the artificial turf field for all intended activities. These warranty exclusions include use of improper cleaning methods or products; normal wear; failure to properly maintain, protect or repair; burns, cuts, accidents, vandalism, or floods; failure of sub-base; use of incorrect grade of infill; failure to maintain infill at correct level; and use of improper footwear or equipment.

6 Case Studies

6.1 Artificial turf in the civilian sector

6.1.1 Unit 4 School District – Champaign, IL

The Unit 4 School District in Champaign, Illinois, installed a multipurpose field to replace its high school natural turf football field. The research team followed the installation process of this field over the summer of 2018.

This effort included periodic visual survey of the project's progress and interviews with Unit 4's Capital Projects Manager and Project Manager (Ms. Sandra Roesler) for the field replacement, and operations and maintenance (O&M) Field Manager (Mr. Tyler McKinney) regarding technical aspects of the project (8 June 2018).

The primary motivation for choosing to install artificial turf was the potential for increased usage. The previously existing natural turf field required heavy irrigation, reseeding, and fertilizer application, and its use was restricted to nine times a year (only for varsity football games) to maintain the health and aesthetics of the field. All other sports teams were prohibited from using the field for practice, and physical education classes were similarly not allowed to use the field for class-time activities. Once the artificial turf is installed, usage of the field will be expanded to include physical education, band practice, soccer games, junior varsity football, and playoff tournaments (hosted events). Staff expect field usage time to increase to over 50 hours a week. It is unknown if this will be continuous usage throughout the entire school year or an average for non-winter periods.

Though Unit 4 did not require preparation of an LCCA of turf options from bidders, the school district estimated that the cost per capita and per use of artificial turf is less than that of the natural turf field because of the increase in usage. The maintenance costs for the existing natural turf field averaged \$10k per year, significantly less than the average \$75k (including installation and an estimated \$10k annual maintenance) per year for artificial turf. However, since the natural turf field was used by only a handful of students for less than 40 hours a year, the higher cost of artificial turf is expected to be offset by high usage by more students (Huard 2018).

The decisions about artificial turf system type and design, while informed by field requirements to host playoff games and to accommodate multiple activities, were primarily based on the need to acquire a strong warranty for the field. It was a priority for the school district to ensure that, after investing over \$2 million on the installation of the field and surrounding track, a warranty would guarantee the proper inspection, maintenance, and repairs for the field. Bidding companies were required to have been in business for a minimum number of years and have completed a minimum number of projects to ensure that they would honor the warranty for its full term (a concern voiced to them by an experienced artificial turf manager at another local institution). Ultimately, the warranty purchased with the field is for 8 years and is contingent on regulated use and maintenance of the field (i.e., specific athletic footwear, cleaning chemicals and practices, etc.).

Maintenance requirements for the artificial turf are expected to be like those for the natural turf field, in terms of time required, though the maintenance tasks will differ.*

6.2 Artificial turf on Army installations

Interviews completed during this project indicated that many of the Army installations that have adopted artificial turf have done so in response to restrictions on irrigating natural grass playing fields. The lack of sufficient water, coupled with heavy use, turned the fields into “dust bowls.”† In fact, irrigation restrictions are not the only reason why these fields were difficult to maintain with such heavy use. (They also required fertilizer application.) However, the dual need to reduce or eliminate water use and to simultaneously maintain a functioning playing surface was the main reason installations from the following case studies cited for replacing natural grass with artificial turf.

6.2.1 Fort Bragg, NC

Fort Bragg was motivated to replace three of their natural turf athletic fields with artificial turf because irrigation was prohibited. The amount of usage the fields received, combined with weeding and mowing requirements, and

* Personal communication between Amanda T. Rodriguez and Elisabeth Jenicek, ERDC-CERL, and Tyler McKinney, Champaign Unit 4 School District. 8 June 2018.

† Phone communication between Amanda T. Rodriguez, ERDC-CERL, and Theresa Smith, Fort Bragg MWR. 7 September 2018.

with lack of irrigation turned athletic fields into “dust bowls” (Figure 6-1).^{*} Artificial turf allowed for high usage on functioning and covered fields.

Figure 6-1. Hendricks Stadium (left) and Hercules Field (right) before installation of artificial turf.

Source: Google Maps 2018a, Google Maps 2018c

The Fort Bragg sports fields at Towle Courts, Hercules Physical Fitness Center, and Hendricks Stadium, are all multipurpose fields approximately the size of standard football fields (combined football and sidelines) and serve a total of 3,500 people per week on average. Two of the fields were installed in early 2016.

The fields are predominantly used for intramural sports, which are held from 6-9 pm, 5 days a week. The field at Towle Courts is also used to host events, of which one included an 8,000 lb boxing ring, and another held a stage on the field. Both resulted in concerns over compaction of the field foundation. All the fields are open for use 24/7 and are not always closely supervised. There are no restrictions on use when surface temperatures on the fields are high (mostly because peak usage takes place in the afternoon, after the height of heat has passed). However, the use of metal cleats is restricted during intramurals, driving vehicles onto the surface is prohibited (except gator maintenance vehicles), as is the use of sleds or fitness center equipment on the field.

^{*} Phone communication between Amanda T. Rodriguez, ERDC-CERL, and Theresa Smith, Fort Bragg MWR. 7 September 2018.

The installation purchased one U.S. sanitizer (about \$8,000) and two vacuums (about \$7,000 each) to facilitate in-house maintenance. Each field requires about 8 hours of maintenance (vacuuming and UV sanitation) per week, which is done by the onsite outdoor maintenance team. Theresa Smith, Fort Bragg's athletics fields' manager, stated that the fields should probably be sanitized and vacuumed more often based on their usage.*

Quarterly maintenance is accomplished by the field installers, who conduct general compaction, leveling, and rip and tear checks. Crumb rubber is replenished by the installer about once a year. Seams are redone from time to time, but, like crumb rubber replenishment, this is seen as a routine maintenance. One incident on the field required repairs outside of the routine maintenance. A unit drove a vehicle onto the field and dropped a boulder. This caused major depressions that required pulling up sections of the turf carpet, leveling the base, and replacing the turf. This repair cost was estimated at \$9,000.

6.2.2 Fort Huachuca, AZ

Fort Huachuca has an estimated 10 artificial turf installations on base, which include multiple baseball and softball fields, playgrounds, and multipurpose fields that are used for both athletic and community events. The replacement of natural with artificial turf on these fields was part of an installation-wide water conservation project. These projects were part of an overall program that has in aggregate "reduced groundwater withdrawals from the regional aquifer by over 65%" over the past 23 years (Waterwise Program 2018, Capriolo 2010). Furthermore, the design of the artificial turf fields maintains natural hydrology by allowing rainwater to percolate through the soil and recharge the groundwater rather than siphoning it off to the stormwater system (Waterwise Program 2018).

6.2.3 Fort Irwin, CA

Like Fort Huachuca, Fort Irwin installed artificial turf on their Blue Track Field as a water-saving technique and also as a measure to improve athlete safety and avoid injuries common on the uneven natural turf field (Figure 6-2).

* Phone communication between Amanda T. Rodriguez, ERDC-CERL, and Theresa Smith, Fort Bragg. Fort Bragg, 7 September 2018.

Figure 6-2. Blue Track Field prior to replacement with artificial turf in 2016.

Source: Google Maps 2018b

Located in the Mojave Desert, the regional climate and annual precipitation average of about 4.2 in. makes maintaining natural grass costly. In FY15, the 4,842 sq ft natural turf field required “about 8.9 million gallons of recycled water to irrigate” (Ozawa 2016).

Specifications were made to the field’s design to accommodate the region’s climate. The turf carpet is of the Cool Turf model, and instead of recycled crumb rubber, they opted for EPDM infill, which better withstands the extreme heat. Additionally, the drainage system is designed to allow precipitation to percolate to the aquifer unless there is a chance heavy rain event, in which case rainwater will be directed to stormwater drainage (Ozawa 2016). The \$1.6 million installation of the multipurpose field is now used for adult and youth soccer and men and women’s flag football.

6.2.4 U.S. Military Academy, West Point, NY

West Point was motivated to begin replacing their natural grass athletic fields with artificial turf in 1977 with AstroTurf at Michie Stadium’s Blaik Field. Since then, the field has been replaced five more times with newer versions of artificial turf, and applications have been expanded to eight other fields (not including partially covered baseball fields), including an

indoor installation. The major motivation for West Point to expand their application of artificial turf has been to accommodate more hours of use, especially during weather conditions that would restrict use of natural turf. An additional motivation is to more properly ensure field user safety, where excessive use on natural grass caused foundation compaction and bare patches. They consider natural grass to no longer be practical for the usage their fields sustain (Rubbino 2018).

Eight of the locations are multipurpose fields that host games and practices for football, lacrosse, rugby, softball, and baseball, and host commencement and opening ceremonies for marathons. The indoor field is also used for band rehearsal, physical fitness courses, physical training (PT), and Fire Department training. Of all the fields, the indoor field gets the most usage, especially since it can be used during inclement weather and the winter months. Similarly, since regulations limit the conditions under which soldiers can be outside or training, the facility allows soldiers to continue training. However, heavier usage of the field does mean it requires more maintenance and attention.

Routine grooming for the fields is done in house, as needed. Compaction testing is done once a year. Crumb rubber is similarly replenished on an as-needed basis, depending on the amount of usage a field receives and how much snow is plowed off during the winter months. Snow is removed by the in-house maintenance team with snow removal agents and rubber-tipped plows (so as not to damage the field). To collect the crumb rubber captured during snow plowing, the snow is stored in a designated area until it melts, after which the crumb rubber can be collected and redistributed onto the fields.

Though not often, the artificial fields at West Point are watered for various reasons. Watering removes static from the field, limiting the amount of crumb rubber that attaches to athletes' clothes, shoes, and equipment. It is also done for a more thorough grooming process and for aesthetic purposes, making the field look better on camera. Fields are not irrigated for the purpose of temperature regulation. Watering is most often done prior to games, for static removal and aesthetics. Blaik Field requires the most watering. The fields rely on potable water for these uses, and some of fields have irrigation systems.

The fields were all procured with a warranty, which is normally for 8 years. The warranty was especially important in protecting the Academy from assuming the costs of a drainage issue, which resulted from improper installation. The warranty covered the total costs of the repair, because the installers were at fault for not correctly laying the stone base.

The Athletic Facilities Manager of Varsity Athletics at West Point (Michael Rubbino)* estimated the maintenance for the six fields he manages to be a combined \$35k per year. Each field replacement (not including digging up and replacing drainage components) is about \$800k per field. Table 6-1 summarizes the use of artificial turf on Army installations.

Table 6-1. Artificial turf on Army installations.

Location	Field Name and Type	Type	Installed	Uses
Fort Bragg, NC	Towle Courts Field	Multi-sport football field	2010	
	Hercules Physical Fitness Center Field	Multi-sport football field	2016	
	Hendricks Stadium Field	Multi-sport football field	2016	
Fort Huachuca, AZ	Eifler Sports Plaza	Combination softball and football field		Softball and flag football
	Warrior/Sentinel Field			
Fort Hunter Liggett, CA			2008	LXR-PRO-73S; 20,500 http://blog.artificialturfsupply.com/the-united-states-army-goes-green/
For Irwin, CA	Blue Track	Multi-sport football field	2016	
U.S. Army Garrison (USAG) Humphreys, Korea				
USMA, West Point, NY	Blaik Field (Michie Stadium)		1977	
	Blaik Field		2008	

* Phone communication between Amanda T. Rodriguez, ERDC-CERL, and Michael Rubbino, 11-12 October 2018.

7 Summary and Conclusions

7.1 Summary

This report documents an effort to assess the viability of replacing natural turf with artificial turf for purposes of reduced landscape water use. The selection process for turf field surfaces encompasses many factors in addition to the water needs of each option. Users should investigate all relevant factors prior to deciding about this technology. The following is a summary of information discovered during this project.

7.1.1 Irrigation policy

Policy that affects landscape irrigation relates to minimizing potable water irrigation beyond that required to establish vegetation, using temporary irrigation systems. Alternately, installations are encouraged to irrigate where needed using non-potable water sources, to utilize water-efficient landscape material, and to employ WaterSense® certified irrigation equipment.

There are other policies that will affect decisions related to turf field surfaces. These policies relate to the possibility of chemical leaching that may fall under the purview of the Clean Water or Endangered Species Acts. Hydrology and stormwater runoff are affected by Public Law, the EISA 2007 Section 438.

7.1.2 Artificial turf technology

The first generation of artificial turf was developed in the 1960s. Originally called ChemGrass, it came to be known as Astro Turf when it was installed in the Houston AstroDome in 1966. At present there are three recognized generations of artificial turf: 1G is made of tightly-wound nylon fibers, includes no infill material, and is attached to foam backing; 2G is made with polypropylene fibers attached to a carpet-like backing and infilled with sand; 3G is comprised of a layer of crumb rubber over sand, covered by a mixture of polyethylene fibers attached to a carpet-like backing. 3G is the most widely used artificial turf product at this time.

7.1.3 Human health and environmental concerns

Evidence-base studies of human health and environmental effects of artificial turf emerged as early as the 1970s with the 1G products. Some studies are ongoing and research findings vary. Generally, there are few studies to draw from, therefore, this summary should not be interpreted as a conclusion about the relative safety of either turf field surface.

7.1.3.1 Human health

Research studies report that artificial turf temperatures run higher than natural turf and may affect field users. Methods to ameliorate these effects include variables in field construction, watering fields to reduce surface temperature, and limiting the use of fields to times of day when temperature is not excessive.

Joint and concussion injuries, as well as turf burn abrasions, occurred at a higher rate on 1G fields, while more recent studies of 3G surfaces show similar rates of injury as with natural turf. Variables include ambient temperature, shock pads and depth of crumb rubber, pile height, compaction of crumb rubber in high use areas, and field maintenance.

Bacterial infections due to artificial turf fields do not appear to be a concern, particularly with the use of anti-microbial sprays and grooming machines containing UV light.

Studies have been unable to reliably correlate exposure to chemicals found in recycled crumb rubber with human health risks. Concerns relate to ingestion, breathing, and skin contact with an array of chemicals found in recycled rubber. A key study was not released at the time of this report, Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds. Once released, this study should be consulted by anyone considering the use of artificial turf.

7.1.3.2 Environmental concerns

The presence of hazardous chemicals in recycled crumb rubber may have environmental implications. Studies refer to chemical leaching potential as well as bioavailability. Generally, crumb rubber sourced from used tires has been found to release more toxic leachate than non-recycled crumb.

Environmental benefits of artificial turf include reduction in pesticides, fertilizer, and herbicides required to maintain natural turf surfaces. Whereas the repurposing of recycled tires for artificial turf crumb rubber has beneficial outcomes initially, these benefits may be outweighed at the end of life of the field when the installation must ultimately dispose of the material.

7.1.4 Life cycle cost analysis of field surfaces

While reduced costs may not be the motivation for installing artificial turf, it is imperative to conduct an LCCA for comparing different options once the decision to install this technology has been made. It is important to consider the full life-cycle costs of a field, including installation, maintenance, and disposal/replacement, in order to achieve an accurate LCCA. Ensure that realistic ‘available field time’ figures are incorporated in calculating a cost/hour of use for the technologies. Warranty provisions must also be considered as these will correlate with expected life of the artificial turf and, therefore, anticipate the requirement/cost to replace the system.

7.1.5 Case studies

The primary non-Army case study was in close proximity to the authors in Champaign, IL. Project planning information was available, however, lessons learned will be garnered in the years to come after the field has been in use and subject to maintenance and repairs. Army case studies included known artificial turf fields and mostly anecdotal information from personnel currently at the site. These were not the individuals that planned and executed the projects to install the turf.

7.2 Conclusions

Water conservation/saving water was the primary motivation for conducting this study. Conclusions point to the possibility of achieving this goal through retrofit of natural with artificial turf. Water needs of most artificial turf applications are limited to periodic cleaning. Exceptions to this occur in regions experiencing high heat where water is required in order to cool the playing surface to avoid the effects of excessive heat on users.

Increased access to fields is a second motivation that drives selection of artificial turf surfaces. Artificial turf is a clear front runner when fields are required for specific events, and when high usage of fields would damage natural turf fields. This is the case in training environments and for parade

grounds and in areas that experience inclement weather that could render natural turf unusable.

Another motivation for this study was to evaluate reports of adverse health/environmental implications. The extant research on user physical safety indicates equal risk to injury on turf grass and third generation artificial turf playing surfaces. Adverse effects of crumb rubber on humans and the environment are still being studied. The reader should follow-up with the federal study results when released (see section 4.4).

The final motivation is the comparison of costs between natural and artificial turf. Preparing a life cycle cost analysis of each option is imperative if cost is a selection factor. There is little guidance on how to do so. The reader is urged to review Chapter 5, along with the references that informed that chapter, before preparing or requesting economic analyses. This report did not address the possibility of rebates for artificial turf, as have been available recently in California and Arizona. Such an incentive would likely favor the use of artificial turf.

Summary information about artificial turf is not readily available in the literature. Other researchers typically focus on one aspect of the turf, such as health effects or stormwater runoff. This report sought to capture information about as many factors related to the product as were available. Gaps in knowledge are identified so that a user can seek additional references as needed.

Although the initial motivation for this study was to investigate the water-saving potential of artificial turf as compared to natural turf, the information garnered pointed to different motivations for the surface. Natural turf can be difficult to maintain in both areas of high and low rainfall. Large amounts of rain can leave natural turf fields unusable due to puddling or the possibility of damage to the turf while waterlogged. Regions with little rain will draw heavily on irrigation. In both situations artificial turf will offer increased access to fields. This access is important when fields are required for military training and as parade grounds. These functions cannot easily be rescheduled or relocated. Artificial turf remains a viable option for indoor applications, though users should follow the same recommendations provided in this report as for outdoor applications.

7.3 Improving the study

This study could be improved by including more case studies, both within and outside of the Army, and lessons learned from artificial turf projects. The study team learned anecdotally of artificial turf ‘failures’ at non-military sites, however, investigation of these was beyond the scope of this project. Installations considering the use of artificial turf are urged to fully explore the technology before making any decisions by using the topic areas of this report as a guide.

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Acronyms and Abbreviations

Term	Definition
1G	First Generation
2G	Second Generation
3G	Third Generation
4G	Fourth Generation
A&E	Architect and Engineer
ACSIM	Assistant Chief of Staff for Installation Management
AMC	U.S. Army Materiel Command
AR	Army Regulation
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ATSDR	Agency for Toxic Substances and Disease Registry
BaP	Benzo[a]pyrene (BaP)
BYU	Brigham Young University
CalEPA	California Environmental Protection Agency
CDC	Center for Disease Control
CEQ	(White House) Council on Environmental Quality
CERL	Construction Engineering Research Laboratory
CPSC	Consumer Product Safety Commission
CTB	Cement-Treated Base
DA	Department of the Army
DHHS	Department of Health and Human Services
DoD	U.S. Department of Defense
EHP	Environmental Health Perspectives
EISA	U.S. Energy Independence and Security Act of 2007
EO	Executive Order
EPDM	ethylene propylene diene M-class [rubber]
ERCIP	Energy Resilience and Conservation Investment Program
ERDC	U.S. Army Engineer Research and Development Center
ERDC-CERL	Engineer Research and Development Center, Construction Engineering Research Laboratory
ESPC	Energy Savings Performance Contract
FEMP	Federal Energy Management Program
FY	Fiscal Year
g	grams
HIC	Head Injury Criterion
hrs./year	hours per year
ILA	Industrial, Landscape, or Agricultural
IMCOM	U.S. Army Installation Management Command
in.	inches

Term	Definition
LCCA	Life-Cycle Cost Analysis
LLC	Limited Liability Corporation
m ³ /kg	cubic meters per kilogram
MCA	Military Construction, Army
mg/kg	milligrams per kilogram
MILCON	Military Construction
MOA	Memorandum of Agreement
MRSI	Methicillin-resistant <i>Staphylococcus intermedius</i>
NCAA	National Collegiate Athletic Association
ng/m ³	nanograms per cubic meter
NILU	Norwegian Institute for Air Pollution
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
NSF	National Science Foundation
NYSDOH	New York State Department of Health
O&M	Operations and Maintenance
OASA(IE&E)	Office of the Assistant Secretary of the Army, Installations, Energy, and Environment
OEHHA	Office of the Environmental Health Hazard Assessment
OMB	Office of Management and Budget
oz.	ounces
oz./yd.	ounces per yard
PAH	Polyaromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
PCDD	Polychlorinated Dibenzodioxin
PDF	Portable Document Format
PE	Polyethylene
PNNL	Pacific Northwest National Laboratory
PT	Physical Training
PU	Polyurethane
RIVM	(Netherlands) National Institute for Public Health and the Environment
SBR	Styrene Butadiene Rubber
SGW	Synthetic Grass Warehouse
sq ft	square feet
STMA	SportsTurf Managers Association
TR	Technical Report
TURI	Toxics Use Reduction Institute
UFC	Unified Facilities Criteria
URL	Universal Resource Locator
USACE	U.S. Army Corps of Engineers
USAG	U.S. Army Garrison

Term	Definition
USAR	U.S. Army Reserves
USC	U.S. Code
USEPA	U.S. Environmental Protection Agency
UV	Ultraviolet
VOC	Volatile Organic Compound
wt/day	weight per day
µg/m ³	micrograms per cubic meter

Appendix A: Summary of Potential Health Risks Associated with Chemicals Released by Crumb Rubber

Windward Environmental conducted a literature review of potential health risks based on chemicals released by crumb rubber (in both indoor and outdoor applications) for the school and park districts of Bainbridge Island, Washington, and calculated cancer and non-cancer health risks for children and teenagers using their own exposure scenario and the highest chemical concentration levels reported in studies they cited (see Tables A-1 and A-2). The review concluded that “human health risks from playing on artificial turf is minimal, even though low concentrations of some chemicals have been demonstrated to leach from the tire crumb or volatilize as vapor” (Johns 2008).

In a health risk assessment done by the Norwegian Institute of Public Health on ingestion, inhalation, and absorption of recycled crumb rubber on artificial turf fields (using worst case scenario exposure levels) found that while “recycled rubber granulate contains many chemical substances which are potentially harmful to health, ... concentrations of these substances are ... extremely low, ... [and] only leached from the rubber granulate in very small quantities” (Johns 2008). They concluded “use of artificial turf ... [for] children, older children, juniors, and adults ... does not cause any elevated health risk” (Johns 2008).

Table A-1. Excess cancer risks associated with playing on artificial turf fields.

Chemical	Excess Cancer Risks Across All Exposure Routes							
	Child				Teenager			
	Inhalation	Dermal Adherence	Incidental Ingestion	Total	Inhalation	Dermal Adherence	Incidental Ingestion	Total
Acetaldehyde	6×10^{-11}	nd	nd	6×10^{-11}	1×10^{-10}	nd	nd	1×10^{-10}
Arsenic	nd	9×10^{-8}	6×10^{-9}	9×10^{-8}	nd	2×10^{-7}	4×10^{-9}	2×10^{-7}
Benzene	4×10^{-7}	7×10^{-10}	nd	4×10^{-7}	1×10^{-6}	2×10^{-9}	nd	1×10^{-6}
Benzo(a)pyrene	5×10^{-8}	2×10^{-10}	2×10^{-11}	5×10^{-8}	1×10^{-7}	5×10^{-10}	1×10^{-11}	1×10^{-7}
Bis(2-ethylhexyl) phthalate	7×10^{-9}	2×10^{-10}	2×10^{-11}	8×10^{-9}	2×10^{-8}	6×10^{-10}	1×10^{-11}	2×10^{-8}
Carcinogenic PAHs	5×10^{-7}	4×10^{-9}	3×10^{-11}	5×10^{-7}	1×10^{-6}	1×10^{-8}	2×10^{-11}	1×10^{-6}
Total PCBs	nd	6×10^{-11}	2×10^{-9}	2×10^{-9}	nd	1×10^{-10}	1×10^{-9}	2×10^{-9}
Source: Johns 2008. Note – Total cancer risks are calculated as the chance that an individual's cancer risk would increase based on a particular exposure. For example, a risk of 1×10^{-6} is equal to 1 in 1,000,000 and a risk of 1×10^{-11} is equal to 1 in 100,000,000,000. According to USEPA guidance, unacceptable cancer risks are those where an individual's excess cancer risk would be increased by more than 1 in 1,000,000, or 1×10^{-6} . nd – no data available for either the exposure concentration or for the toxicity of the contaminant								

Table A-2. Non-cancer hazard quotients associated with playing on artificial turf fields.

Chemical	Non-Cancer HQ							
	Child				Teenager			
	Inhalation	Dermal Adherence	Incidental Ingestion	Total	Inhalation	Dermal Adherence	Incidental Ingestion	Total
Acetaldehyde	0.06	nd	nd	0.06	0.07	nd	nd	0.07
Arsenic	nd	0.005	0.0003	0.05	nd	0.005	0.0001	0.005
Bis(2-ethylhexyl) phthalate	nd	0.00002	0.000002	0.00002	nd	0.00002	0.0000005	0.00002
Benzene	0.006	0.00007	nd	0.006	0.006	0.00007	nd	0.006
Methyl isobutyl ketone	0.0006	nd	nd	0.0006	0.0006	nd	nd	0.0006
Toluene	0.002	0.0002	nd	0.002	0.002	0.0002	nd	0.003
Total PCBs	nd	0.00004	0.001	0.001	nd	0.00004	0.0004	0.0004
Xylene	0.05	nd	nd	0.05	0.05	nd	nd	0.05
Zinc	nd	0.0007	0.0008	0.002	nd	0.0007	0.0003	0.001
Note – Non-cancer risk estimates are calculated as a hazard quotient, with any value greater than 1 considered unacceptable by USEPA. nd – no data available for either the exposure concentration or for the toxicity of the contaminant								

Source: Johns 2008.

Appendix B: Material Composition of Select Artificial Turf Systems

Table B-1. Composition of selected artificial turf products for athletic fields.

Company*	Brands	Fiber Material	Infill Material	Backing Material
FieldTurf	FieldTurf	polyethylene (PE)	silica sand cryo-rubber (3lb/sq ft) Nike Grind	polyurethane (PU)
SprinTurf	Ultrablade XPS MP	PE (44 oz/sq yd) PE (40 oz/sq yd) PE (36 oz/sq yd)	rubber or FlexSand rubber-coated silica sand	Stabilon (10 oz/sq yd) PU (28 oz/sq yd) Stabilon (10 oz/sq yd) PU (20 ox/sq yd) Stabilon (10 oz/sq yd) PU (20 ox/sq yd)
Sofsport	Sofsport	PE (40 oz/sq yd) total wt 70 oz/sq yd	rubber (1.5 lb/sq ft) sand (3.5 lb/sq ft)	polypropylene (2 layer) PU (18-20 oz/sq yd) rubber pad (recycled content?) 10 mm
Forever Green	SmartGrass 5020 XPS 4020L	polyethylene 80 oz/sq yd total wt 70 oz/sq yd total wt	cryo-rubber	Fibrolock™ polyurethane
ProGreen	ProGreen	polyethylene	cyro-rubber	
Sportexe	SportBlade Omnigrass FastGrass VictoryTurf	polyethylene polyethylene nylon Thiolon XPL polyethylene/nylon	50%rubber/50% sand 100% ground rubber Styrene Butadiene Rubber (SBR) SBR	4-layer backing 4-layer backing 2-layer backing 2-layer backing
AstroTurf	AstroPlay AstroGrass PureGrass	polyethylene nylon nylon	rubber no infill or sand infill no infill, SBR, or EPDM rubber	“paved” or foam pad “closed cell” or foam “paved” or foam pad
SafePlay	SafePlay Plus SafePlay Select II	PE (50 oz/sq yd) PE (40 oz/yd)	recycled SBR (4 lb/sq ft) with DuraBond additives recycled SBR (3.3 lb/sq ft) with DuraBond additives	Tribond (10.66 oz/yd) Urethane (24-36 oz/yd) Tribond (10.66 oz/yd) Urethane (24-36 oz/yd)
A-Turf	Premier-RS SportFlex-R	PE (40-50 oz/sq yd) PE (40-50 oz/sq yd)	SBR, silica sand SBR	polypropylene, polyester, fiber, urethane polypropylene, polyester, fiber, urethane
ARMS Building & Maintenance	ProPlay	polyethylene	EnviroFill coated silica sand	polyethylene foam
The Motz Group	24/7 Artificial Field Turf (PE/nylon turf for landscape use)	polyethylene (Thiolon XPS, 41 oz)	coarse sand/rubber or just rubber	granulated rubber (optional)
General Sports Turf	GameDay MP, HD, or XPe	polyethylene	100% SBR or rubber + <10% DiaFill	3-part woven backing + urethane (26 oz)
*Source: Dickey 2007.				

Appendix C: Evaluation of Common Infill Material

Table C-1. Advantages and limitations of the major types of infill material for artificial turf.

type	advantages	limitations	cost	recyclability	field performance
silica sand	a natural mineral mined from gravel pits; durable; does not get very hot from absorbing the heat from the sun.	the playing surface is very hard and abrasive; weights more than the other infill products; compaction can occur; can generate dust.	least expensive	can be recycled or disposed of with little restriction.	widely used in the second generation artificial turf
tire rubber crumb	provides excellent stability, uniformity, and resiliency; proven durability and performance; made from postconsumer recycled materials; does not harden or change composition, allowing the surface to stay consistent over time.	small rubber particles easily stick onto clothes and skin; retains heat from the sun and can get very hot; may release volatile and semivolatile organic contaminants into the air; may leach heavy metals and organic contaminants into water.	more expensive than silica sand	can be recycled or disposed of in landfills	has been field tested and proven for performance over many years
silica sand and tire rubber crumb mixture	provides a firmer playing surface than rubber only infill; mixed infill helps ensure optimal field safety and playability.	segregation of the rubber and sand particles can occur and the mixed infill needs to be loosened periodically.	costs less than rubber only infill	tire rubber crumb can be separated from sand, and subsequently recycled or disposed of in landfills	has been field tested and proven for performance over many years
thermoplastic elastomers	made from virgin materials that do not contain hazardous additives; less heat absorption when exposed to the sun compared to rubber infill.	subject to wide manufacturing variations; may harden over time; some products do not provide enough flexibility and crush resistance; some products do not contain ultraviolet stabilizers and undergo degradation relatively.	very expensive	recyclable	the durability and performance remain to be proven
EPDM rubber	made from virgin material that does not contain hazardous additives; durable and more environmentally friendly than tire rubber; available in a variety of colors; less heat absorption when exposed to the sun compared to rubber infill.	chemicals used in the rubber manufacturing can leach into the contacting water	very expensive	recyclable	has been used in European countries, yet the durability and performance remain to be proven
organic infill	derived from natural plant fibers and cork; nontoxic and truly environmentally friendly; less heat absorption when exposed to the sun compared to rubber infill; resists wear and ultraviolet rays.	requires antimicrobial treatment to prevent degradation; may break down; may be infected by insects; compaction can occur over time.	relatively inexpensive	can be recycled into other products	new to the market, and has no track record for durability
rubber coated sand	does not contain hazardous additives; eliminates the compaction and dust issues of sand; less heat absorption when exposed to the sun compared to rubber infill.	a softer filler material need to be added to the acrylic material; coating may break down over time.	more expensive than sand infill	can be recycled	new to the market, and has no track record for durability

Source: Cheng et al. 2014.

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14. ABSTRACT Artificial turf, long in use on athletic fields in the civilian sector, is finding its way to military installations. This technology can help to meet both training and aesthetic requirements without the irrigation footprint associated with most natural turf fields. With the increased use of artificial turf, particularly in drought-plagued regions, emerge concerns about its potential adverse effects. There is a need for additional information, both on technical performance and cost-benefit analysis, to support decisions about use of artificial turf at Army installations. This work was undertaken to research costs and benefits of both artificial and natural turf materials, and to develop guidelines for making design decisions. This study examined technical, financial, and performance data and recommends best practices for the use of artificial turf.					
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