Holistic Environmental Considerations for Turf Replacement Initiatives

WRIGHT WATER ENGINEERS, INC.

COLORADO
Colorado Water Conservation Board
Department of Natural Resources

June 2024

ACKNOWLEDGEMENTS

The Colorado Water Conservation Board provided financial and technical support for completion of this white paper under the leadership of:

Russ Sands, Section Chief – Water Supply Planning
Jenna Battson, Outdoor Water Conservation Coordinator

Wright Water Engineers, Inc., prepared this report, with authors including:

Jane Clary, LEED AP, CPESC
Andrew Earles, P.E., Ph.D., P.H.
Natalie Collar, Ph.D., CFM
Matthew Howard

WWE acknowledges the input and practical experiences shared by:

Catherine Moravec, Colorado Springs Utilities
Bea Stratton, Denver Water
Rick Shultz, Town of Castle Rock
Aditi Bhaskar, Ph.D., University of Colorado Boulder
Colorado State University Extension (multiple publications)

TABLE OF CONTENTS

TABLES

Figures

Appendices

1.0 INTRODUCTION

Transformative landscape change is a strategy included in the Colorado Water Plan to reduce urban landscape water usage. The Colorado Water Conservation Board (CWCB) has supported this strategy through various efforts, including promoting Water Efficiency Plans, reducing water loss, and focusing on One Water Strategies (including alternative water supplies). Recently there has been increased interest in providing grant funding to support new and existing community programs aimed at helping eligible entities replace nonessential turf to reduce outdoor watering, per legislation passed in 2022. This funding has been targeted to entities such as local water providers who can manage nonfunctional turf replacement incentive programs (https://cwcb.colorado.gov/turf). CWCB has also funded similar efforts through other grant programs such as the Water Plan Grant Program.

Additionally, in 2022, the Colorado River Basin Municipal and Public Water Providers (including Denver Water, Aurora Water, Pueblo Water, and Castle Rock Water) signed a Memorandum of Understanding (MOU) related to water consumption, including landscape-related practices. Specific commitments related to landscape transformations included:

- *Introduce a program to reduce the quantity of non-functional turfgrass by 30% through replacement with drought- and climate-resilient landscaping, while maintaining vital urban landscapes and tree canopies that benefit our communities, wildlife, and the environment.*

- *Implement best practices and share lessons learned to help one another accelerate our efficiency strategies. Water providers will select from the following approaches those tactics best tailored to preserve thriving communities, environmental health, and strong economies: […] Transforming our outdoor landscapes and urban environments in a manner that improves climate resilience and promotes an ethic of wise water use through mandatory watering schedules and compliance enforcement, incentivized turf removal, and limitations on new turf […]*

Various local governments such as Aurora, Castle Rock, Broomfield and others have passed ordinances limiting turf in new developments, with other local governments also in the process of revising landscape codes. Other local governments such as Denver and Lafayette have internal initiatives focused on replacing non-functional turf in public spaces (Booth, 2023). While water conservation is the primary goal of these initiatives, many local governments also recognize the multiple benefits of landscapes in urban areas (i.e., the intent is to transform landscapes, not remove them.)

Turf conversion projects involve the replacement of irrigated turfgrass with alternative landscapes that require and receive less water. These lower water landscape alternatives are often referred to as “water-wise” landscaping, Xeriscaping or ColoradoScaping. CWCB has supported follow-up studies related to the water conservation benefits of turf conversions, including the 2024 BBC Research and Consulting (BBC) report titled “Updated 2024 Exploratory Analysis of Potential Water Savings, Costs and Benefits of Turf Replacement in Colorado.” BBC estimated potential annual water savings of 20,000 acre-feet if one-third of the estimated 167,800 acres of irrigated turf in Colorado is converted to water-wise landscapes (BBC, 2024).

While the potential benefits of reduced water consumption from turf conversion projects have been well documented, other effects of turf conversion related to rainfall-runoff, stormwater quality, urban heat island effects, pollinator effects and community acceptance have been less well studied. In 2024, CWCB tasked Wright Water Engineers, Inc. (WWE) to prepare this white paper to explore potential unintended environmental consequences of turf replacement programs that should be considered as CWCB pursues water conservation strategies in accordance with the Colorado Water Plan. Inherent in this scope is recognition that a holistic environmental view is needed in terms of how turf conversion projects are implemented, what turf landscapes are converted to, and how transformed landscapes are maintained into the future (see Photographs 1- 6 for several positive and negative examples). Goals of this white paper include summarizing current knowledge regarding environmental considerations for landscape conversions, identifying data gaps that should be filled by future research, and summarizing best practices for holistic environmental benefits related to turf conversion.

WWE conducted the following tasks to prepare this white paper:

1. Reviewed literature and conducted interviews related to water quality, hydrologic and urban heat island effects of turf conversion projects. Although considerations related to pollinators, carbon sequestration and community values were somewhat beyond the scope of this project, these topics are also briefly discussed, referencing recent work by others.

2. Summarized recent research related to hydrologic effects of water-wise landscaping practices from work for the Mile High Flood District (MHFD) and the City of Aurora. Based on this information, WWE conducted new modeling to estimate hydrologic changes associated with various landscape conversions at several locations around Colorado.

3. Synthesized literature and recent research to identify best practices for turf conversions to maximize holistic environmental benefits and minimize effects on water quality, hydrology and urban heat island effects.

4. Identified areas where additional research and/or guidance would be beneficial to better mitigate potential unintended consequences of turf conversion projects and to maximize holistic benefits of such projects.

This paper is organized as follows:

- Overview of landscape transformation alternatives and turf removal methods.
- Overview of water quality issues related to landscape transformation alternatives focused on herbicides, nutrients, sediment and temperature.
- Analysis of hydrologic changes associated with landscape transformations.
- Urban heat island considerations related to alternative landscapes.
- Brief discussion of pollinator effects, carbon sequestration considerations and community values and acceptance considerations for landscape transformations.
- Summary of findings and recommendations.
- Research needs to further understand environmental considerations for landscape transformations.

Photo 1. Colorado Springs Utilities' ColoradoScape demonstration garden. See link for more.

Photo 2. Year 2 of a residential turf to water-wise landscaping conversion with ground cover establishing.

Photo 3. Showy milkweed pollinator habitat in a residential turf to water-wise landscape conversion.

Photo 4. Native grasses in a public park that are periodically mowed but not irrigated or fertilized.

Photo 5. Poorly maintained, weedy residential rock area, which was previously an irrigated turf area.

Photo 6. Commercial parking lot median converted to rock and bare ground with irrigation still occurring and running off into gutter, along with broken sprinkler heads.

2.0 TURF CONVERSION ALTERNATIVES

Multiple alternatives for replacing irrigated turf can be considered in landscape transformation projects such as native grasses, wood mulch Xeriscape with plantings, gravel mulch Xeriscape with plantings, western desert landscaping, artificial turf, permeable pavements, and hardscaping. Terms such as water-wise landscapes, Xeriscape, and ColoradoScape are generally used interchangeably to generally describe such landscape conversions. All three of these terminologies share common principles that are rooted in the seven principles of Xeriscape, which is a trademarked term coined by Denver Water in the 1980s. Briefly, these principles include:

1. Planning and designing for water conservation, beauty, and utility.
2. Improving the soil, as needed to support healthy vegetation.
3. Watering efficiently with appropriate irrigation methods.
4. Hydrozoning (grouping plants with similar water needs together).
5. Mulching to reduce evaporation.
6. Creating practical turf and non-turf areas.
7. Maintaining the landscape with good horticultural practices.

Vegetated Urban Landscape Benefits
(Johnson, Koski and O'Connor 2017)

- Conserving biodiversity in the environment
- Protecting soil and water resources
- Sequestering carbon
- Cleaning the air and creating oxygen
- Mitigating stormwater runoff
- Connecting people with nature
- Improving personal fitness, healing and learning
- Encouraging outdoor recreation
- Discouraging violence and crime
- Preserving historic outdoor spaces
- Supplying local fresh food
- Alleviating the urban heat island effect

For purposes of this report, the terms Xeriscape and ColoradoScape are used relatively interchangeably with more focus on the specific landscape cover type. Examples of specific landscape cover types from the Denver Turfgrass Study (City and County of Denver, 2024) include:

- Traditional turfgrass
- Rock mulch
- Wood mulch
- Drought tolerant "turf-like" ground covers
- Native grass, wildflower, and forbs seed mixes

- “ColoradoScaping” with native and adaptive shrub, grass, and perennial plantings

Other practices that could be part of turf landscape conversions include:

- Permeable pavements (e.g., interlocking concrete block pavers)
- Hardscaping
- Artificial turf
- Stopping or reducing turf irrigation without replacing with alternative cover

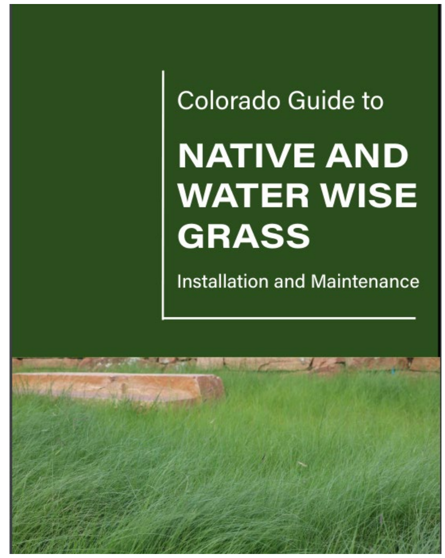


Photo 7. Native Grass Working Group’s Colorado Guide to Native and Water Wise Grass Installation and Maintenance.

Regardless of the type of land cover (e.g., vegetation, hardscape) selected, the success of any turf conversion project depends on more than replacing a “high water” plant type with plants or surface cover with lower water requirements. If the irrigation levels are not adjusted and maintained to meet the lower water use demand of the new ground cover, water savings cannot be achieved. Even water-wise or Xeriscape plants can be over-irrigated, reducing the effectiveness of turf conversions. The Native Grass Working Group has prepared a guide that addresses installation and maintenance practices for turf to native and water-wise grass conversions (Native Grass Working Group, 2024; Photo 7). As a few examples of considerations that go beyond simply changing plant species, the success of turf conversions includes considerations such as:

- **Weed management**—both in terms of initial establishment of the replacement vegetation and over the long-term, weed management is a key component of turf conversion projects. The owner of the new landscape needs to be informed, prepared and capable of managing the new landscape. Once established, maintenance requirements are typically lower than manicured turf; however, zero maintenance is not a reasonable expectation. While hand-pulling weeds may be a realistic for homeowners on smaller lots, weed management can be a major undertaking for large landscape conversions (Koski 2024).

- **Soil amendment**—during initial stages of turf conversion projects, it’s important to understand whether soil amendment will be needed to support the new landscape or whether new plantings can occur in existing topsoil. The turf conversion process itself can affect the type of soil amendment needed. Soil testing is inexpensive, readily available (https://agsci.colostate.edu/soiltestinglab/) and is highly recommended. Guidance on soil amendment and soil testing is available in multiple existing guidance documents such as through CSU Extension (Davis et al., 2024) and the Mile High Flood District’s Topsoil Guidance (MHFD, 2020).

- **Irrigation management**—for water conservation savings to be realized for turf conversion projects, irrigation practices must be adjusted. This could involve replacing a spray irrigation system with a drip system, decreasing irrigation frequency and rates for an existing system, or ceasing irrigation coverage of certain areas (e.g., hardscape).

- **Maintenance and Communication for Community Acceptance**—a clear maintenance plan, implementation of maintenance activities, communication and messaging to communities are important aspects of turf conversion projects, particularly in public spaces. Examples of communication may involve signage relating to dead grass during the turf conversion project, signage explaining the "more natural look" associated with alternative landscapes, etc. Similarly, communities and HOAs should have realistic expectations that it may take a few years for the new landscape to become well established, with critically important maintenance related to weed management and temporary irrigation during establishment. Failed projects (e.g., due to weed infestations) can serve as a deterrent to future projects. Additionally, failed vegetation can result in living landscapes later being replaced with hardscape/rock that has some negative environmental consequences, as discussed later in this report.

From a water conservation perspective for new construction, selection of plants with lower water requirements as opposed to non-functional irrigated turf areas is an obvious choice for decreasing a development's "water footprint." For existing irrigated turfgrass areas being considered for conversion, it is possible that changing *how* existing turfgrass is managed can also be a way to increase the water efficiency of the landscape. For example, in 2015, WWE, Northern Water and Aquacraft (2015) quantified the benefits of various landscape best management practices. A few representative findings included:

- … reducing over-irrigation by 20% for single family residential units and 10% for multi-family residential units could save nearly 86,560 AF of water in the South Platte Basin over a 40-year period.

- Warm-season turfgrass (e.g., Buffalograss) had lower water requirements than the other cool-season turfgrass scenarios except with regard to the scenario that represented use of soil amendment and irrigation management using a more advanced "manage allowable depletion" (MAD) approach for cool-season turfgrass. This analysis suggests that an aggressively managed cool-season turfgrass with proper soil amendment may achieve water savings comparable to or greater than warm-season turfgrass, depending on the management strategy implemented. This is an important finding because GreenCO (WWE 2008) and Colorado State University Turf Program both recommend that turf selection should be based on the desired functional, recreational and aesthetic benefits, in addition to considering maintenance and water requirements. For example, cool-season turfgrass is desirable for certain landscape purposes, such as for high use areas, whereas warm-season Buffalograss has lower traffic tolerance and may be more suitable for low-traffic areas.

- For cool-season turfgrass (e.g., Kentucky bluegrass) management scenarios, the lowest water use resulted for the scenario represented by soil amendment and aggressively managed irrigation using a MAD approach, which typically requires advanced irrigation technology…. This scenario reduced the irrigation requirement by nearly 50% relative to the baseline turf scenarios under an average water year. This scenario approaches the water savings achieved by drip-irrigated annuals and is similar to warm-season turf. In summary, the irrigation management practice at a site is a critical factor in the irrigation requirement. This may represent a significant opportunity for savings on large landscapes or highly managed commercial landscapes, even if this is not directly transferable to the average homeowner.

There may be circumstances where a turf conversion project may not be the best fit (e.g., lack of community acceptance, inadequate resources to complete a proper conversion project, timing related to drought conditions), but there may still be opportunities to reduce water usage, such as the opportunities described above. As an example, allowing a bluegrass lawn to "go natural" in a less manicured (e.g., taller grass height, less irrigation) may be an option as a temporary measure to test community acceptance of a different landscape type (Koski, 2024). For example, a development in the Town of Castle Rock has allowed grass medians to be maintained in a less irrigated, natural condition (Schultz, 2023; Photo 8). As another example, although Kentucky bluegrass will "use" 24-26 inches of irrigation per growing season, it can be grown with 15-20 inches of irrigation, if a lower quality lawn with some brown spots is acceptable (Koski, 2006). These gradual transitions from manicured turf can be a good option during active drought conditions when a turf replacement project is not desirable due to the initial irrigation needed for establishment of new water-wise plants.

Photo 8. Naturalized Kentucky bluegrass in a median in Castle Rock (Source: Rick Schultz, Town of Castle Rock).

Lastly, development itself is a form of landscape conversion that covers pervious land with buildings, roads, and other impermeable surfaces. Moreover, this transformation is happening alongside new turf removal programs which means there is a cumulative loss of green space. As development occurs to provide housing and services for Colorado's communities, it is important that pervious, living landscapes are planned and managed wisely to maximize environmental and community benefits. Considerations include not only water conservation but also community values, rainfall-runoff effects, water quality, urban heat island effects, biodiversity and other factors. With limited pervious areas in the urban environment, it is important that the pervious areas that remain in developed areas provide multi-faceted community benefits whether the land cover consists of irrigated turf, native grasses, or other types of permeable landscaping.

Lastly, this white paper is not intended to go into detail on water-wise landscape techniques and strategies that have been covered in extensive resources prepared by Colorado State Extension and others (see text box for additional resources).

Colorado State Extension Water Wise Landscape Resources
(Source: https://cmg.extension.colostate.edu/gardening-resources/online-garden-publications/water-wise-landscaping-xeriscaping/)

- **Basics**
  - Learning More about Xeriscaping – Planttalk #1904
  - Xeriscape Basics – Planttalk #1901
- **Design**
  - Water Wise Landscape Design: Design Principles – CMG GardenNotes #413
  - Water Wise Landscape Design: Design Steps – CMG GardenNotes #411
  - Xeriscaping: Creative Landscaping – Fact Sheet #7.228
  - Xeriscape Design – Planttalk #1902
- **Maintenance** – Xeriscape Maintenance – Planttalk #1910
- **Plant Selection**
  - Annuals Xeriscape: Annuals and Perennials – Planttalk #1909
  - General Xeriscape Plant Choices – Planttalk #1907
  - Ground Covers Xeriscaping: Ground Cover Plants – Fact Sheet #7.230
  - Ornamental Grasses Xeriscape Ornamental Grasses – Planttalk #1906
  - Perennials Xeriscape: Annuals and Perennials – Planttalk #1909
- **Trees and Shrubs**
  - Xeriscape Trees and Shrubs – Planttalk #1911
  - Xeriscaping: Trees and Shrubs – Fact Sheet #7.229
- **Turf and Alternatives**
  - Water Wise Landscape Design: Selecting Turf Options – CMG GardenNotes #412
  - Xeriscape Turf and Alternatives – Planttalk #1912
  - Xeriscaping: Trees and Shrubs – Fact Sheet #7.229
- **Retrofit Your Yard** – Xeriscaping: Retrofit Your Yard – Fact Sheet #7.234
- **Soil Amendments** – Xeriscape Soil Amendments – Planttalk #1908

3.0 TURF CONVERSION METHODS

The manner in which turf conversions are implemented can affect short-term water quality (e.g., sediment transport) and the success of the turf conversion over the long term (e.g., soil health). Although this white paper is not intended to provide detailed guidance on turf conversion methods, a summary of methods is provided to identify general pros and cons of chemical versus mechanical methods. Best practices continue to evolve on this subject. Therefore, this discussion is also supported by an active case study at the U.S. Airforce Academy to illustrate lessons learned.

Resources for Turf Conversion Methods

Colorado Native Grass Working Group

CSU PlantTalk Lawn Conversion

Resource Central

Wild Ones Front Range

3.1 Overview of Methods

Table 1 summarizes various turf removal methods based on review of resources developed by the Native Grass Working Group (2024), Colorado State University Extension, Resource Central, City of Fort Collins Utilities, and Wild Ones Front Range Chapter (2023).

Based on interviews conducted in support of this white paper, the general consensus is that large-scale turf conversion projects, such as those conducted by local governments on public property, likely require herbicides. While some efforts are being piloted to remove turf without chemicals, this does not currently have wide adoption for large projects, can be costly, and creates waste (e.g., dirt and sod that is removed) that may not always be able to be composted. A range of non-chemical methods may be feasible on smaller projects (<100 sq. ft. up to 1,000 sq. ft.).

Table 1. Overview of Common Turf Conversion Methods

Method	Brief Description	Pros/Cons
Herbicide	Water existing plants to promote active growth phase. Spray with a non-selective herbicide (e.g., glyphosate) until turf and weeds are dead. Typically, herbicide is applied 2 to 3 times over a span of 2 months.	Pros • Less labor intensive • Fast (~2 months) • Dead grass serves as fertilizer and temporary erosion control • Effective for both large-scale and small-scale projects • Maintains soil microbial activity • Maintains soil structure • Most effective way to eradicate weeds Cons • Health/environmental concerns are debated • May not be allowed in some jurisdictions
Mechanical: Sod Cutter	Mow and water lawn. Cut overlapping strips through grass, thatch, and roots and roll sod to remove.	Pros • Fast and effective for turf removal • Suitable for small to mid-scale projects • Safe for health/environment Cons • May damage soil structure • May reduce soil microbial activity • Requires equipment & labor • Requires that lawn is in good health • Produces large amounts of waste • May not remove weed rhizomes • Labor intensive/costly for large applications
Solarize	Saturate lawn with water and cover the lawn with clear plastic for 1 to 2 months to kill plant life. Do not till after to avoid regermination of weeds. (A variation of this method is opaque “silage tarps.”)	Pros • Inexpensive and effective • Dead grass serves as fertilizer and temporary erosion control • Safe for health/environment • Maintains soil microbial activity • Maintains soil structure Cons • Slow • May not be practical for large projects • Aesthetic concerns by HOAs

Method	Brief Description	Pros/Cons
"Lasagna" Method or Sheet Mulching (aka "Mow Close and Cover")	Closely mow the grass and water, then apply layers of materials such as wet cardboard, newspaper and other materials followed by a mulch layer to kill the lawn and allow decomposition to occur in place.	Pros • Inexpensive • Does not require special equipment • Safe for health/environment • Leftover organic content acts as fertilizer • Maintains soil microbial activity • Maintains soil structure Cons • Time-consuming (may require 2-3 seasons) • Effectiveness is questionable
Mechanical: Dig it Up	Water lawn thoroughly and fully remove grass, thatch, and roots with hoe or other mechanical equipment. Cover with soil and mulch.	Pros • Viable for small scale projects • Safe for health/environment Cons • Labor intensive/impractical for large scale projects • May damage soil structure • May limit soil microbial activity • Weed seeds brought to surface may germinate
Tilling	Till when soil is warm and saturated (damp) from recent rain. Till in layers (e.g., break up grass, then thatch, then roots). Perform in fall when dead grass will fertilize soil.	Pros • Suitable for small-scale projects • May maintain soil microbial activity • Safe for health/environment Cons • Requires special equipment • May damage soil structure • Weeds brought to surface may germinate • Effectiveness is seasonally dependent
Stress Lawn & Plant Shrubs	Stress lawn by not watering and use lawn mower at shortest length setting to scalp lawn. Plant native shrubs close together to create continuous cover that prevents weeds and grass from receiving sunlight. Only water shrubs.	Pros • Inexpensive and minimal labor • Maintains soil microbial activity and soil structure • Organic content from decomposing lawn acts as fertilizer • Provides ecological value to insects and wildlife Cons • Limited to small scale projects • Slower and requires supervision for success • Effectiveness dependent on shrub health

Note: Other methods not shown in this table include steaming and flaming, as discussed by Fontanelli et al., 2017; these methods require special equipment.

3.2 Colorado Springs Utilities and U.S. Airforce Academy Turf Conversion Case Study

In 2023, Colorado Springs Utilities and the U.S. Airforce Academy (USAFA) began a project to identify and test water-wise grass types for potential turfgrass replacement projects. The project is focused on ornamental, irrigated landscaping locations, as opposed to non-irrigated natural areas or ecological restoration projects. The project team replaced the existing high water use turfgrass on the north side of the Civil Engineering Building with eight different types of alternative grass species and mixtures being irrigated at about half of the irrigation that the traditional turfgrass areas receive (Figure 1). The turf removal method for the project was sod-cutting followed by addition of soil amendment in the form of compost from nearby horse stables. Over the next few years, the project team will continue to evaluate appearance, winter hardiness, salt tolerance, and maintenance needs (mowing, fertilizing, aerating) to determine which options are preferred for future projects at USAFA (Weiss and Moravec 2023).

Figure 1. Colorado Springs Utilities Grass Trials at the U.S. Airforce Academy
(Source: Weiss and Moravec 2023)

Although the study is not yet complete, several lessons learned are already available from this case study. Weiss and Moravec (2023) have identified these initial findings:

- Weeds were initially an issue, and weed management was identified as a significant consideration for turf conversion projects.

- Native grasses take longer to fully establish than traditional turfgrass sod. By the end of the 2023 growing season, the grasses covered approximately 30 to 60 percent of the bare ground of each plot, which is considered "meeting expectations" for native grass establishment during the first season.

- With an active management plan for watering, weed control, fertilizing, mowing, and overseeding bare patches, all plots are expected to reach 80 to 100 percent cover by the end of the 2024 growing season.

- The soil amendment that was added to the area after the turfgrass removal may be causing some of the grasses to underperform. Test results showed the soil in the grass trials area was considerably saltier and had remarkably higher pH and organic matter content compared to the controls. Most Colorado native grasses do not grow well in highly organic, high pH, or salty soils, as these conditions rarely occur in natural areas of the state.

- The cost of the various grass species ranged from $42/1,000 square feet for a native prairie grass seed mix to $140/1,000 square feet for the buffalograss seed and the buffalograss/inland saltgrass mixture.[1] As part of the project initial establishment of the project in 2023, labor hours were closely tracked with the following breakdown reported for the 7,000 square foot area:

    - Site preparation – 4 people for 24 hours with equipment
    - Planting – 8 people for 3 hours
    - Weed control – 25 hours
    - Overseeding – 2 hours
    - Monitoring irrigation – 5 hours

- The progress report for the project includes more detailed information on seed mixes and a project monitoring plan that may be useful for others embarking on similar pilot projects.

As part of follow-up discussions with Catherine Moravec, Colorado Springs Utilities, two additional takeaways related to water quality considerations include:

- A downside to an herbicide-free approach to turf replacement is that bare soil is exposed for a longer period of time and more susceptible to erosion as well as seed displacement. Additionally, there are likely practical limits to the size of a project that can be undertaken

[1] Although not explicitly addressed in the progress report, an additional consideration for turf replacement in public spaces relates to the intended function of the turf and resilience to foot traffic, which may vary based on seed mix.

without herbicide use. Planting seed in dead grass has the benefit of providing “mulch” for planted seed, as opposed to the bare soil condition following sod-cutting.

- On-going sharing of experiences from projects like this one will help to further refine best practices for turf to native grass conversions that can then be shared with local governments and be incorporated into training for landscape industry professionals. Training needs to include all phases of such projects including grass species selection, turf removal, soil preparation and seeding, weed management and irrigation. The current state of the practice for these conversions has been described as “the Wild West.”

3.3 Summary of Recommendations for Turf Conversion Methods

For residential and small-scale turf removal projects, successful turf removal approaches can include both non-herbicide (manual/mechanical approaches) and herbicide approaches. When herbicides are used, product labels must be followed (“label is the law”) to minimize potential adverse water quality, ecological and human health effects. Be aware that some local regulations either do not allow or severely restrict herbicide use. (See more detailed discussion of herbicide use in Section 4.1.)

For larger scale projects, turf removal projects will often require or benefit from the use of herbicide.[2] Herbicide application must be in accordance with the label and should be applied by a certified pesticide applicator. Based on lessons learned from large-scale conversion projects, drill-seeding into dead turf may be the preferred turf conversion approach for native grasses because it provides temporary soil/seed cover, reduces susceptibility to erosion and requires less soil amendment (assuming underlying soils are determined to be of sufficient quality). Sod-cutting would be the second approach that may be viable up to a certain scale, depending on project budgets.

Depending on the method used to remove turf, temporary erosion and sediment control measures may be needed to mitigate effects of exposed soils until vegetation is established. For large-scale turf conversion projects that disturb one acre or more of area, CDPHE’s General permit for Stormwater Discharges Associated with Construction Activities may be required.

4.0 POTENTIAL WATER QUALITY EFFECTS OF TURF CONVERSION

Water quality effects of turf conversion projects vary depending on the condition and management of the existing landscape and the type of landscape transformation implemented. Turf landscapes and alternative water-wise landscapes can have both positive and negative effects depending on the installation and management practices associated with the new landscape. Representative considerations that are discussed further in this white paper include:

- **Herbicides:** Effects of herbicide use in traditional turfgrass and alternative landscapes is highly site-specific. Generally, landscapes that use minimal herbicide reduce the potential

[2] This statement is not intended to be an endorsement of chemical application from CWCB; instead, it reflects typical practice unless there are specific prohibitions on chemical use in those communities.

for herbicides in runoff. Varying viewpoints and considerations for this topic are discussed in more detail in Section 4.1.1 below.

- **Nutrients/Fertilizer:** Nitrogen and phosphorus originating in lawn irrigation driven surface runoff from residential catchments has been shown to be an important contributor of nutrients in surface waters (Fillo et al., 2021; Toor et al., 2017; McPherson et al., 2005; Stein and Ackerman, 2007). Fertilizer application to traditional turf landscapes can increase nutrient sources present in watersheds; however, the extent of transport of those nutrients to waterbodies depends on fertilizer management practices and the amount, timing, and type of fertilizer applied along with proper application practices. For example, several statewide and regional initiatives are underway to encourage citizens to choose phosphorus-free fertilizers for established lawns to reduce phosphorus loading to impaired waterbodies such as Barr Lake, Cherry Creek Reservoir and Bear Creek Reservoir (e.g., SPLASH, Colorado Stormwater Council, Colorado Water Wise).

- **Sediment:** Healthy turf and sod-forming native grasses help to slow and filter sediment and sediment-associated pollutants from urban runoff. (Turf and native grasses are often components of stormwater control measures such as grass swales and buffers.) Exposed soil from unhealthy turf, intentional vegetation removal with no replacement, or poorly revegetated turf conversions can become sources of sediment and associated pollutants transported in urban runoff.

- **Temperature:** Vegetated surfaces help to mitigate temperature-related effects of urbanization in both water temperature and air temperature, whereas hardscapes tend to retain heat.

- **Hydrologic Changes:** Section 5 discusses the potential hydrologic changes associated with turf conversion projects in detail; however, wet weather and dry weather hydrology is also briefly summarized below since it relates to pollutant transport:

    - **Wet Weather Runoff Rates and Volumes:** Vegetated landscapes such as turf or sod-forming native grasses slow runoff velocities, allow infiltration of runoff in urban areas, and help to filter pollutants from urban runoff. As described by the Mile High Flood District (MHFD) in its Urban Storm Drainage Criteria Manual Volume 3, runoff reduction by disconnecting impervious surfaces and promoting infiltration into pervious surfaces is the first step in managing stormwater quality in runoff from development (MHFD 2024). (This topic is discussed in detail in Section 5 below.)

    - **Dry Weather Flows:** Irrigated turf may contribute dry weather urban runoff to storm sewer systems, creating nuisance "urban drool" and transporting pollutants such as bacteria and nutrients. Fillo et al. (2021) found that lawn irrigation comprised 32% (+/-10%) to 82% (+/- 21%) of baseflow in urban streams in the Denver area, with an overall average of 59%. Properly managed turf with well-maintained irrigation systems following a water budget and adjusted seasonally to meet the needs of the plants will have less dry weather runoff than those that are not well managed (e.g., overapplication and overspray). Water-wise landscapes with limited (e.g., drip), infrequent, or no irrigation will result in less dry weather flow.

4.1.1 Herbicides

While there are a variety of methods for removing turf as discussed in Section 3, application of glyphosate is the most commonly used method, particularly on large-scale projects (Moravec, 2024; Schiavon et al., 2013). During a turf conversion project, glyphosate is typically applied two to three times to kill the existing turf. When glyphosate is properly applied in accordance with label instructions in a short-term application such as turf removal, research shows minimal risks from terrestrial or water pathways and that the benefits generally outweigh the risks (EPA, 2024 [see text box]; Moravec, 2024; see Appendix A).

U.S. EPA's Current Position on Glyphosate

(Source: https://www.epa.gov/ingredients-used-pesticide-products/glyphosate)

Glyphosate is a widely used herbicide that controls broadleaf weeds and grasses. It has been registered as a pesticide in the U.S. since 1974. Since glyphosate's first registration, EPA has reviewed and reassessed its safety and uses, including undergoing registration review, a program that re-evaluates each registered pesticide on a 15-year cycle.

In February 2020, after receiving and considering public comments on the glyphosate proposed interim decision (ID), EPA published the interim decision registration review decision for glyphosate. As part of this action, EPA found that there are no risks of concern to human health when glyphosate is used in accordance with its current label. EPA also found that glyphosate is unlikely to be a human carcinogen. The ID also identified potential ecological risks to non-target organisms, primarily non-target plants through spray drift. The ID identified interim risk mitigation measures in the form of label changes, including spray drift management language, herbicide resistance management language, a non-target organism advisory, and certain label consistency measures. It concluded that the benefits of glyphosate outweigh the potential ecological risks when glyphosate is used in accordance with labels.

Due to legal actions on March 20, 2020, and June 17, 2022, EPA is further reviewing the ecological portion of the registration review. EPA's underlying scientific findings regarding glyphosate, including its finding that glyphosate is not likely to be carcinogenic to humans, remain the same. In accordance with the court's decision, the Agency intends to revisit and better explain its evaluation of the carcinogenic potential of glyphosate and to consider whether to do so for other aspects of its human health analysis. For the ecological portion, EPA intends to address the issues for which it sought remand, including: to consider whether additional or different risk mitigation may be necessary based on the outcome of Endangered Species Act consultation for glyphosate, prepare an analysis of in-field effects of glyphosate on monarch butterfly habitat, consider whether there are other aspects of its analysis of ecological risks and costs to revisit, and consider what risk mitigation measures may be necessary to reduce potential risk following completion of analyses left outstanding in the ID.

Despite EPA's interim decision regarding glyphosate, opposing viewpoints remain regarding glyphosate use in the scientific literature. Concerns related to glyphosate use relate to environmental risks including changes to the behavior of honeybees and phytoplankton community structure and human health effects, such as endocrine-related effects and potentially cancer (Medalie et al., 2020). Internationally, the International Agency for Research on Cancer classified glyphosate as a probable human carcinogen (International Agency for Research on Cancer, 2015); however, the European Food Safety Authority concluded this classification is not supported (European Food Safety Authority, 2015). (Note: Resolution of these issues is beyond the scope of this white paper.)

Some local governments in Colorado (e.g., City of Boulder, Boulder County) and in other states (e.g., Los Angeles County) restrict glyphosate use and/or have reduction goals (City of Boulder, 2024; Boulder County, 2024; Chiotti et al., 2020, 2020; Bounds, 2024). The Southern California Coastal Water Research Program (SCCWRP) convened an expert panel to evaluate alternatives to glyphosate use (Alternatives to Glyphosate for Vegetation Management in Los Angeles County) (Chiotti et al., 2020). The study concluded that most alternatives to glyphosate had label restrictions and warnings, and there was not a “winner” for a better alternative (Chiotti et al. 2020). Similarly, herbicide trials in the context of turf removal have been conducted in Colorado to identify alternative chemical approaches to turf removal. To date, these studies are inconclusive on whether a better alternative that is still effective is viable. A potential downside to replacing glyphosate with other methods is that less effective herbicides may require more chemical application to achieve the same results (Koski, 2024).

From a water quality perspective, the key question related to glyphosate and other herbicide usage relates to how it mobilizes and is transported in water once applied. When glyphosate is properly applied, it and its byproduct AMPA tends to sorb to the soil rather than mobilize in runoff. Of note is that glyphosate and its byproduct AMPA contain phosphorus (Medalie et al., 2020). Because of the relatively low mobility of glyphosate in the environment once it is applied, it is difficult to estimate herbicide loading to streams and lakes, particularly when herbicides are applied from land, as opposed to aerial applications.

In lieu of estimating herbicide transport in this white paper, WWE has calculated an estimated amount of glyphosate that could potentially be applied to achieve a 30% turf removal objective in the Colorado River Basin MOU. Actual rates may be lower for small scale applications where mechanical turf removal approaches can be used more easily.

Table 2. Estimated Range of Glyphosate Applications to Achieve 30% Turf Removal Target in Colorado River Basin MOU

Region	Irrigated Turf Approx. Area (acres) (from BBC 2024)	30% Turf Conversion Target (acres)	Estimated Glyphosate Application (lbs) to Remove 30% Irrigated Turf		
			Mid Rate	Low Rate	High Rate
DRCOG Region	104,800	31,440	94,320	62,880	157,200
North Metro (Larimer & Weld Counties)	21,000	6,300	18,900	12,600	31,500
South Front Range (El Paso & Pueblo Counties)	26,700	8,010	24,030	16,020	40,050
Non-Front Range (Grand Junction, Durango, others)	15,300	4,590	13,770	9,180	22,950
Total	167,800	50,340	151,020	100,680	251,700
Assumptions based on personal communication with Catherine Moravec, June 2024: In general, turf conversions are assumed to require 2-3 applications of glyphosate to kill existing vegetation at 0.75 to 1.5 lbs acid equivalent (a.e.) per acre. The 0.75 to 1.5 lbs per acre is the rate used for most agricultural applications. The range of assumptions include: • Low scenario would be 2 applications at 0.75 lbs a.e./acre + spot spraying • Medium scenario would be 3 applications at 0.75 lbs a.e./acre • High scenario would be 3 applications at 1.5 lbs a.e./acre					

After the initial herbicide application to kill the turfgrass, there is limited data on how much glyphosate or other herbicide application over the long term may be reduced by converting irrigated turf areas to other types of landscapes since both turfgrass and water-wise landscapes experience weeds. Data from Colorado Springs Utilities indicates that annual applications of glyphosate for post-emergent weed control may be reduced from 0 – 4 times per year for turfgrass to 0 – 2 time per year for native grass (Moravec, 2024); however, other types of turf replacements such as wood or gravel mulch with sparse plantings could require more application of glyphosate for weed management than turf. Additionally, river rock or gravel beds that replace turf often experience weed growth.

Recommended conservation practices related to pesticides (inclusive of herbicides) in the Colorado Department of Natural Resources sponsored study completed by Armstead et al. (2024) included avoiding or minimizing the use of pesticides with management practices including integrated pest management, pesticide risk reduction and integrated weed management. Although native landscapes are well suited to reduced herbicide use once established, experience has shown that it may be necessary to used herbicides for effective turf conversions at larger scales.

4.1.2 Nutrients and Sediment

4.1.2.1 General Overview

As part of the Colorado Water Quality Control Commission's 10-year Water Quality Roadmap for Colorado (https://cdphe.colorado.gov/water-quality-10-year-roadmap), nutrient-related water quality issues are a high priority for wastewater treatment, urban stormwater runoff, and agricultural runoff (non-point sources). The Commission has established total phosphorus and total nitrogen standards for streams and lakes in Colorado that are in various stages of implementation through a phased regulatory process. Control regulations are in place to limit nutrient loading to reservoirs such as Cherry Creek Reservoir, Chatfield Reservoir, Bear Creek Reservoir and Lake Dillon. Additionally, Barr Lake and Milton Reservoir have a Total Maximum Daily Load (TMDL) that focuses on phosphorus reduction as a strategy to achieve water quality standards in the reservoirs. Several watershed organizations such the Barr-Milton Watershed Association, Cherry Creek Basin Water Quality Authority, Colorado Stormwater Council and others recognize landscape management and lawn conversion as potential source control practices to reduce nutrient loading. Some current efforts focus on use of phosphorus-free fertilizer and irrigation efficiency for established lawns, and there is interest in better understanding how much nutrient loading in urban runoff could be reduced by conversions of lawns to landscapes requiring less fertilizer application and irrigation.

Nutrients and sediment in urban runoff from developed areas can contribute to pollution of streams and lakes in Colorado. Under Municipal Separate Storm Sewer System (MS4) permits, local governments are required to implement a range of practices to minimize pollutant loading from developed areas. Controlling erosion during construction activities, implementing stormwater control measures (also known as SCMs or BMPs), and implementing source controls are a few key components of these programs. Landscaped areas are generally favorable to urban stormwater management objectives because their pervious surfaces allow slowing and infiltration of runoff and filtering of pollutants. "Receiving pervious areas" such as grass buffers and swales are recognized as stormwater control measures when they meet the requirements specified in storm drainage criteria manuals (MHFD 2024)[3] and MS4 permits (CDPHE 2020). Conversely, landscaped areas can also contribute to pollution depending on irrigation, fertilizer and other maintenance practices.

[3] The Mile High Flood District (2024) Urban Storm Drainage Criteria Manual Volume 3 notes that in many settings utilizing receiving pervious areas as a stormwater control measure, native turf grasses are a more sustainable option than non-native, irrigated turf grasses. Sod-forming native grasses are preferred over bunch grasses for stormwater quality features. During establishment of receiving pervious areas used for stormwater quality purposes, irrigation is required following planting to achieve required vegetation density in a timely manner and may be needed during drought periods. After the grass is established, irrigation requirements for native grasses can be reduced. For extended detention basins, native grasses (and other vegetation) can be used. Alterations to vegetation in established stormwater quality control measures requires consultation with municipal stormwater managers to ensure that the function of the facility is being maintained.

Some of the environmental benefits and tradeoffs of turfgrass lawns include:

- Healthy, sod-forming turfgrass allows infiltration and filtering of runoff and reduces transport of sediment and associated pollutants. Dense native grasses also provide these functions.

- Improperly irrigated lawns (e.g., overspray, excessive watering) can result in conditions that convey pollutants under both wet and dry weather conditions, including nuisance "urban drool." Saturated soils in heavily irrigated lawns have less infiltration capacity. Conversely, an inadequately irrigated landscape can be subject to soil erosion and weed infestations.

- Improperly applying or overapplying fertilizer can result in nutrient transport in both dry and wet weather conditions. Conversely, an unhealthy, sparse lawn with exposed soil can result in sediment transport (as noted above for irrigation) and weed infestations.

- During turf conversion projects, exposed soil (such as following sod-cutting) can be susceptible to erosion and sediment transport. To minimize erosion and sediment transport during turf conversion projects, erosion and sediment control measures should be implemented and left in place until the new landscape has reached a stabilized condition. Examples, particularly for large scale projects, include perimeter control measures such as straw wattles or silt fences, and steeper slopes may require additional stabilization measures such as erosion control blankets, particularly on larger scale turf conversion projects. (See MHFD [2024] for guidance.)

- During turf conversion projects, be aware that glyphosate includes approximately 18.3% phosphorus by mass, and its degradation byproducts such as aminomethylphosphonic acid (AMPA) contain phosphorus. This phosphorus, although a minor source relative to fertilizers, persists in the environment and can influence soil phosphorus accumulation and losses to surrounding freshwater systems (Hebert et al. 2018).

Given variables such as those described above, generalizations regarding nutrient transport from lawns can be difficult. The focus of organizations such as Colorado State Extension, Colorado Stormwater Council, GreenCO (WWE 2008) and others has generally been on educating property owners and landscape professionals on proper fertilizer application to maintain healthy vegetation and practices to minimize fertilizer transport in surface water and groundwater (Table 3). Nonetheless, some property owners may not be aware of or follow best practices; therefore, actual practice may be highly variable based on the property owner and the type of property management (e.g., individual homeowner, municipality).

In terms of quantities of nitrogen and phosphorus in fertilizer applied to non-functional irrigation turf landscapes that could be mobilized to waterways, WWE did not attempt to provide an estimate for purposes of this white paper due to lack of appropriate data and the range of assumptions required to complete these calculations. Instead, WWE notes the following:

- Phosphorus is not typically needed in fertilizer for established lawns in Colorado. Thus, if property owners change management practices to select phosphorus-free fertilizer, then this "source control" practice would address concerns about phosphorus transported in runoff from urban lawns. In other words, the phosphorus benefits of turf conversion may be neutral (i.e., “a wash”), depending on existing fertilizer practices.

- Based on Colorado State University Extension recommendations, nitrogen fertilizer application requirements for lower-water turfgrasses such as buffalograss, blue grama and bermudagrass are lower than for traditional bluegrass lawns. (Note: suitability of these alternative turfgrasses depends on the intended function of the lawn and level of foot traffic, along with other factors.) For example, these grasses may require one-quarter of the nitrogen application recommended for a high maintenance bluegrass lawn. Transport of applied nitrogen in stormwater, however, would depend on other factors (e.g., see footnotes in Table 3).

Table 3. Colorado State University Extension’s Recommended Nitrogen Fertilizer Application Schedule for Established Colorado Lawns
(Source: Koski and Skinner 2012)

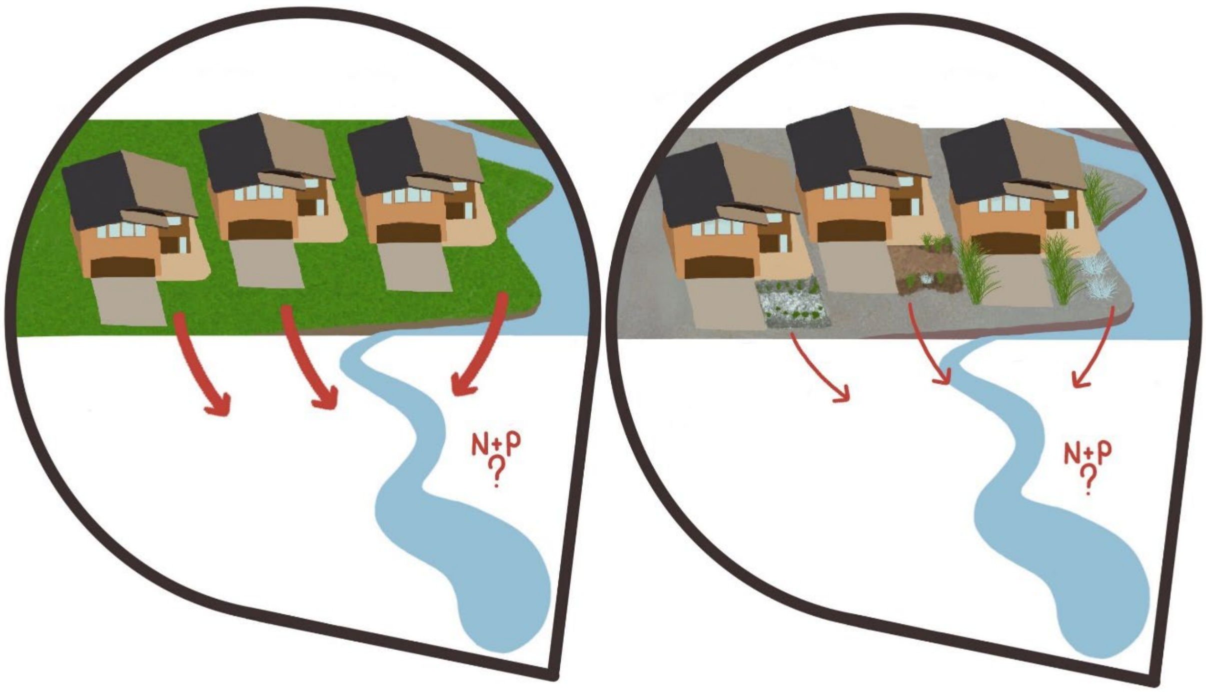
Turfgrass Species	Mid-March to April[1]	May to mid-June	July to early August	Mid-August to mid-September	Early October to early November[2]
(nitrogen application rates are in pounds of nitrogen per 1,000 square feet of lawn area)					
High Maintenance Bluegrass/Ryegrass	1/2-1	1	not required	1	1-(2 optional)
Low-Maintenance Bluegrass	1/2	1/2-1	not required	1	(1) optional
Turf-Type Tall Fescue	1/2	1/2-1	not required	1	(1) optional
Fine Fescue	1/2	1/2-1	not required	1/2-1	not required
Buffalograss/Blue Grama/Bermudagrass	Apply no N	1/2-1	1/2-1	Apply no N	Apply no N

[1] The March-April nitrogen application may not be needed if fertilizer was applied late (September to November) the previous year. If spring green-up and growth is satisfactory, delay fertilizing until May or June.
[2] Apply when grass is still green.

- Optional nitrogen applications shown in ( ). Use extra nitrogen applications where a higher quality turf is desired or on heavily used turf.
- Make the final fall nitrogen application (October-November) while the grass is still green and at least two to three weeks before the ground begins to freeze in your area.
- On very sandy soils, do not fertilize turf after late September. Nitrogen can leach into groundwater during the winter months. Use slow-release nitrogen fertilizers (sulfur-coated urea, IBDU and natural organic-based fertilizers) on sandy soils throughout the year to reduce the potential for leaching losses.
- Nitrogen application can often be reduced by 1/4 to 1/3 when grass clippings are returned to the lawn during mowing. Nitrogen and other nutrients contained in the clippings are recycled into the lawn as they decompose.

Beyond the general principles described above, the quantitative benefits of various landscape covers related to nutrient transport are not well documented. In 2024, CWCB funded a research project to further understanding of nutrient loading from various landscape transformation alternatives (Bhaskar, 2024) that should help to refine this understanding so that the water conservation and water quality synergies (and potentially trade-offs) of turf conversion can be better quantified. This will help to advance understanding of the role that landscape transformations may play in meeting the nutrient reduction goals for various watersheds in Colorado. In lieu of specific landscape cover data for nutrients in urban runoff, the subsections below provide an overview of available Colorado and national data related to nutrients in urban runoff.

Figure 2. Conceptualization of Changes in Nutrient Loading from Traditional Turfgrass and ColoradoScape Development Styles (Source: Bhaskar, 2024)



4.1.2.2 Colorado and National Nutrient Research

Nutrients in urban runoff include nutrients present in rainfall and nutrients transported from the landscape surface. Generally, infiltration of runoff into pervious surfaces helps reduce nutrient transport to streams and lakes. Long-term rainfall monitoring in the Cherry Creek Watershed shows median total phosphorus concentrations in rainfall of 0.07 mg/L and median total nitrogen concentrations of 1.95 mg/L (https://www.ccbwqportal.org/). In Rocky Mountain National Park nitrogen concentrations in rainfall ranged from 0.007 to 1.29 mg/L at a site near Bear Lake (Mast et al. 2003). Concentrations may vary across the state, but the point remains that rainfall itself is a source of nutrients; therefore, infiltrating rainfall into landscapes is preferable to runoff from hardscapes.

As part of the 10-year Water Quality Road Map, the CDPHE Water Quality Control Division (WQCD) required Colorado MS4s to complete a “data gap analysis” under Regulation 85 to characterize available information related to nutrient concentrations for urban runoff according to various land uses. This resulting report summarized national and Colorado-based data for nutrients (WWE et al., 2013). Findings from that report were subsequently added to the National Stormwater Quality Database (Pitt et al., 2018) and utilized to support regional criteria manuals such as the MHFD’s Urban Storm Drainage Criteria Manual, Volume 3. To support an ongoing study for the Cherry Creek Basin Water Quality Authority, WWE recently updated the phosphorus data set compiled by WWE et al. (2013). Tables 3 and 4 and Figures 1 and 2 provide ranges of total phosphorus and total nitrogen in urban runoff by land use. Commercial, highway and industrial sites were determined to be similar for phosphorus based on prior statistical analysis, therefore, they have also been grouped for purposes of boxplots. For both phosphorus and nitrogen, residential land uses have higher concentrations than the commercial-highway-industrial group. Open space runoff only has seven samples from the Denver Regional Urban Runoff Program (DRURP) in the 1990s. WWE reached out to Colorado State University Extension and USDA researchers to determine whether additional prairie runoff data might be available, but none were identified in Colorado. Although these open space concentrations are similar to residential runoff, runoff volumes during frequently occurring precipitation events are typically lower than urban areas; therefore, nutrient *loading* from open space land uses would be lower despite comparable concentration to residential areas. (Hydrologic considerations are discussed in Section 5.3.)

Table 4. Total Phosphorus (mg/L) in Urban Runoff in Colorado
(Source: WWE et al. (2013), updated by WWE in 2024)

Land Use	Count	Minimum	Maximum	1st Quartile	Median	3rd Quartile	Mean
Commercial, Highway & Industrial (COM-HWY-IND)	487	0.01	6.30	0.13	**0.26**	0.45	**0.39**
Open Space (OPEN)	7	0.21	0.66	0.26	**0.41**	0.54	**0.41**
Residential (RES)	498	0.04	3.40	0.23	**0.37**	0.63	**0.48**

Figure 3. Boxplots of Total Phosphorus (mg/L) in Urban Runoff in Colorado

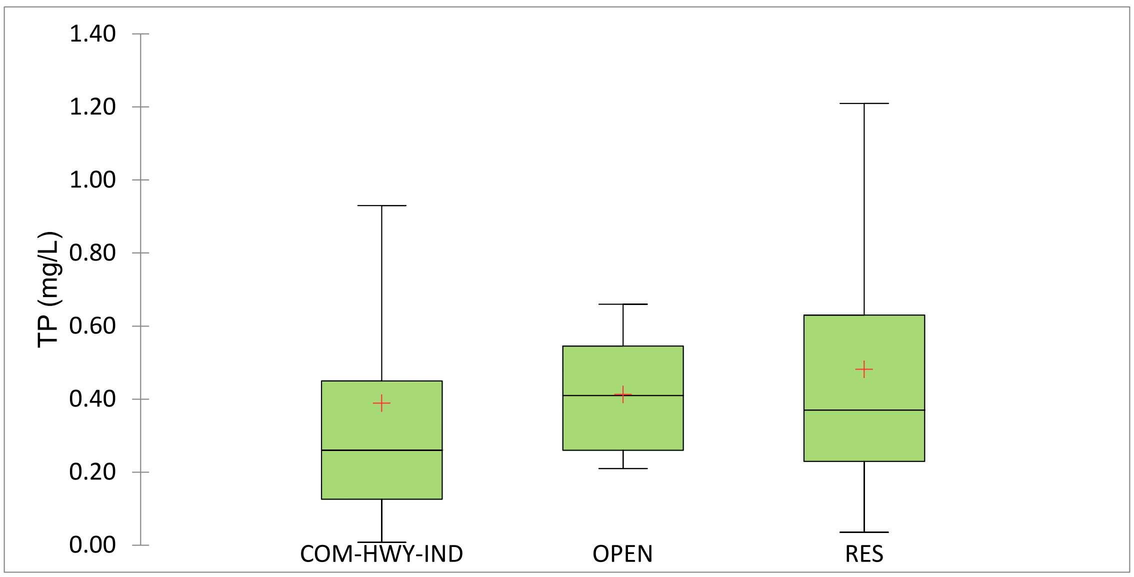
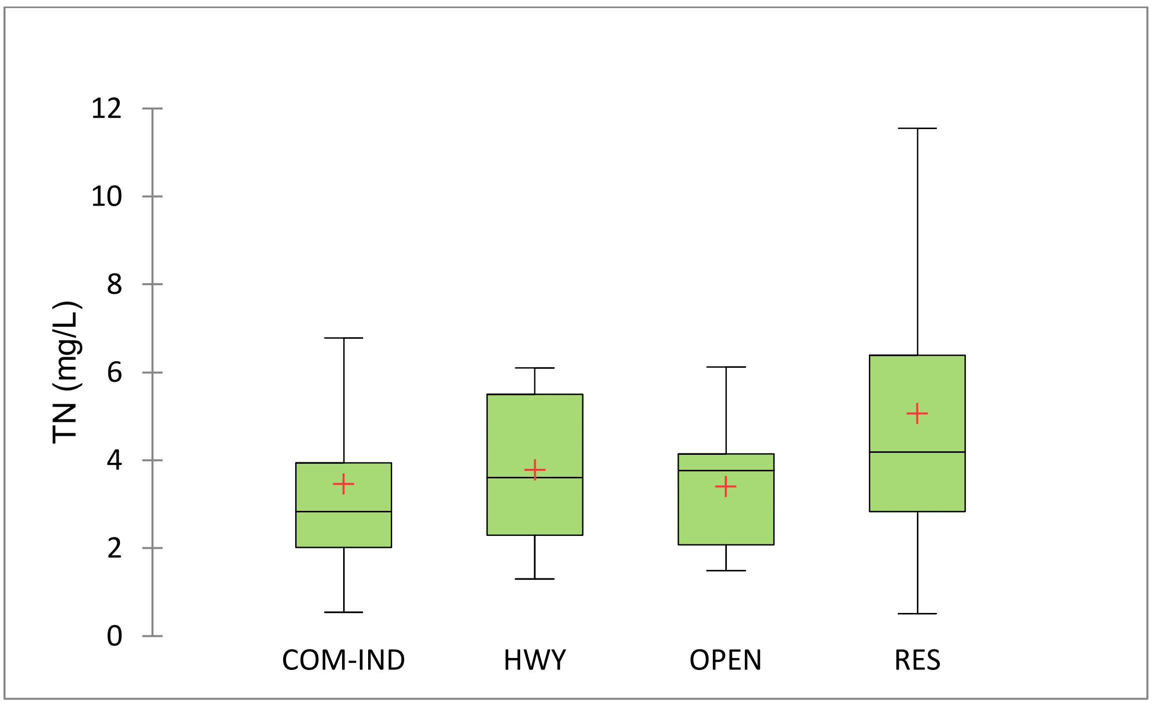


Table 5. Total Nitrogen (mg/L) in Urban Runoff in Colorado
(Source: WWE et al., 2013)

Land Use	Count	Minimum	Maximum	1st Quartile	Median	3rd Quartile	Mean
Commercial & Industrial (COM-IND)	191	0.54	16.63	2.01	2.84	3.93	3.47
Highway (HWY)	9	1.30	6.10	2.30	3.60	5.50	3.78
Open Space (OPEN)	7	1.49	6.12	2.08	3.76	4.14	3.40
Residential (RES)	191	0.51	22.77	2.83	4.19	6.38	5.06

Figure 4. Boxplots of Total Nitrogen (mg/L) in Urban Runoff in Colorado



The available data described above imply that manicured turf areas common in residential areas are likely to have higher nutrient loading in urban runoff than native grasses common in open spaces. However, inadequate information exists to quantify the typical range of nutrient concentrations by specific land cover types in Colorado. Although the tables and figures above could be useful for bracketing typical potential ranges of nutrients, monitoring is needed to draw more refined conclusions about specific landscape covers. In such studies, it will be important to document metadata such as soil condition, irrigation practices, fertilization practices, density of vegetative cover, aspect, and other conditions that affect vegetation health.

Due to lack of Colorado-specific nutrient runoff concentration data for specific landscape types, other national research for pollutant source areas was reviewed. WWE identified two compilations of runoff data that help to quantify nutrients and sediment from landscaped areas compared to other sources. The first is work by Pitt, Clark and Williamson (2004) who conducted a national literature review to characterize runoff from various source loading areas. They noted limited availability of data for runoff from landscaped areas. Their findings are summarized in Table 6. These data indicate that small landscape areas have higher concentrations for most nutrients in sheet flow runoff than other land uses, including undeveloped areas. For several nutrients, average concentrations in runoff from landscape areas range from double the concentration to an order of magnitude higher than other land uses.

The second source is work by the USGS in Wisconsin, as summarized in Table 7. The USGS summary shows pollutant concentrations from specific land cover types and the overall basin outfall. Table 7 indicates that residential lawns are sources of nutrients in urban watersheds, with grass areas having the highest total Kjeldahl nitrogen and total phosphorus concentrations. Additionally, from a mass loading perspective relative to the overall basin outlet, grass areas were a major contributor of total Kjeldahl nitrogen (31 percent) and total phosphorus (26 percent), even though the runoff volume generated from grass areas was low (5.8 percent) (Steuer et al., 1997).

More recently, Carey et al. (2012 and 2013) reviewed turfgrass fertilizer management practices with implications for urban water quality, including nutrient loading rates from various types of landscapes. A key finding was that fertilizer management practices significantly influence nutrients in runoff from various landscapes.

Although these data sources are older and outside of Colorado, they still provide a frame of reference that indicates that lawns can be significant sources of nutrients in urban runoff. Colorado communities would benefit from updated water quality sampling data for specific landscape types in Colorado that go beyond general land use categories (e.g., residential, commercial). Reduction in nutrient loading from landscapes is a potential area of synergy related to water conservation and water quality objectives in Colorado.

Table 6. Mean Concentrations of Selected Pollutants Associated with Sheetflow for Various Source Areas

(Adapted from Pitt, Clark and Williamson 2004 in ©CHI2004 www.computationalhydraulics.com)

Source Area	TSS (mg/L)	TDS (mg/L)	P, Total (mg/L)	P, Dis. (mg/L)	TKN (mg/L)	Kjeldahl N, Dis. (mg/L)	Nitrite + Nitrate N (mg/L)
Residential Roofs							
Sample Count	81	38	87	82	7	7	8
Average	**36.7**	**60.8**	**0.17**	**0.07**	**1.10**	**0.80**	**0.68**
Commercial Roofs							
Sample Count	34	19	19	31	7	7	9.0
Average	**32.8**	**115.0**	**0.18**	**0.06**	**2.00**	**1.65**	**0.75**
Industrial Roofs							
Sample Count	42	42	9	9	n/a	n/a	n/a
Average	**15.8**	**60.8**	**0.13**	**0.02**	**n/a**	**n/a**	**n/a**
Commercial Parking							
Sample Count	44	21	42	39	5	5	7
Average	**130.0**	**62.7**	**0.20**	**0.06**	**1.20**	**0.58**	**0.40**
Industrial Parking Lots							
Sample Count	90	89	40	36	n/a	n/a	19
Average	**244.0**	**1002.0**	**0.39**	**0.09**	**n/a**	**n/a**	**0.41**
Driveways							
Sample Count	69	19	69	65	9	9	9
Average	**154.0**	**111.0**	**1.00**	**0.29**	**2.60**	**0.69**	**0.45**
Small Landscape Areas							
Sample Count	40	13	42	39	4	4	4
Average	**227.0**	**183.0**	**2.20**	**1.35**	**10.50**	**1.97**	**0.45**
Commercial Streets							
Sample Count	75	50.0	74.0	65	16	15	16
Average	**176.0**	**123.0**	**0.31**	**0.06**	**3.70**	**0.90**	**0.49**
Residential Streets							
Sample Count	131	32	132	127	5	4	5
Average	**183.0**	**116.0**	**0.66**	**0.30**	**1.00**	**0.52**	**0.40**
Industrial Streets							
Sample Count	15	15	15	15	n/a	n/a	n/a
Average	**894.0**	**170.0**	**1.30**	**0.46**	**n/a**	**n/a**	**n/a**
Freeways							
Sample Count	66	11	21	20	10	10	10
Average	**138.0**	**94.4**	**0.24**	**0.08**	**1.30**	**0.49**	**0.78**
Undeveloped Areas							
Sample Count	5	5	5	3	5	5	2
Average	**16.0**	**186.2**	**0.08**	**0.01**	**1.10**	**0.88**	**0.03**

Notes: TDS = total dissolved solids; TSS = total suspended solids: P = phosphorus; TKN = total Kjeldahl nitrogen; N = nitrogen. Sample count is the number of samples collected.

Table 7. Source-Area and Basin Outlet Geometric Mean Concentrations of Selected Properties and Constituents for Urban Basins in Marquette, Michigan and Madison, Wisconsin
(Source: Steuer, Selbig, Honewer and Prey 1997)

	Streets			Rooftops		Parking Lots/Driveways		Lawns	Outlet
Analyte/Data Source	High-traffic	Medium-traffic	Low-traffic	Residential Rooftop	Commercial Rooftop	Commercial Parking Lot	Residential Driveway	Residential Lawns	Basin Outlet
TSS (mg/L)									
Steuer et al. 1997	251 (226)	323 (305)	206 (175)	36	24	138 (110)	178 (157)	262	159
Bannerman et al. 1993	232	326	662	27	15	58	173	397	262
Washbusch 1994-1995	117	79	104						
Ammonia-N (mg/L)	0.44 (0.42)	0.35	0.26	0.46 (0.44)	0.72 (0.67)	0.19 (0.22)	0.12	0.26	0.20
Nitrate plus Nitrite (mg/L)	0.46 (0.45)	0.32	0.27	0.54 (0.46)	0.57 (0.49)	0.3 (0.34)	0.30	0.40	0.37
TKN (mg/L)	2.3 (2.5)	1.3	0.9	1.3 (1.0)	1.7 (1.6)	1.5 (1.6)	1.8	9.3	1.5
Total Phosphorus (mg/L)									
Steuer et al. 1997	0.29 (0.31)	0.24 (0.23)	0.14	0.08 (0.06)	0.09	0.21 (0.20)	0.35	2.33	0.29
Bannerman et al. 1993	0.47	1.07	1.31	0.15	0.20	0.19	1.16	2.67	0.66
Washbusch 1994-1995	0.19	0.19	0.41						

Table Notes:
Coefficients in parentheses identify geometric mean with unreliable concentration data removed.
Steuer et al. 1997 notes: USGS 1994 study in Marquette, MI.
Bannerman and others, 1993 notes: (High-traffic street 19,800-20,000 vehicles per day; Medium-traffic street 500-7,300 vehicles per day; Low-traffic street 100-400 vehicles per day)
Waschbusch 1994 - 1995 notes: traffic-Monroe Street (18,600 cars per day; commercial on-street parking); medium traffic-Glenway Avenue (6,157 cars per day; limited on- street parking); low traffic-Monroe Street (378 cars per day; residential).

4.1.3 Temperature (Thermal Water Pollution)

Closely related to the urban heat island effects discussion later in Section 6, landscape choices can also affect thermal water pollution. WWE performed a literature review to understand what impact, if any, various landscaped surfaces (e.g., pea gravel, wood mulch, turf, concrete, etc.) have on thermal pollution loading transferred via runoff. As runoff sheds from impervious urban surfaces like asphalt roads, which reach temperatures as much as 27°C to 50°C greater than the air temperature, it is heated before discharging to surface waters where it can affect the metabolic and reproductive health of aquatic species (USEPA, 2008). Thermal pollution from urban runoff is well studied for pervious and impervious surfaces, but the heat transfer dynamics of the previously mentioned landscaping surfaces are not thoroughly understood.

Several studies have noted substantial differences in temperatures of runoff shed from impervious surfaces like asphalt and concrete as opposed to pervious surfaces like turf. A 2008 study of turfgrass and asphalt plots found that the total heat transported via runoff from asphalt-only surfaces was 3.6 times greater compared to total runoff heat transport from turf-only surfaces; a mixed asphalt-turfgrass surface exported 38% less total heat than the asphalt-only surface (Thompson et al., 2008). USEPA (2008) reports differences in runoff temperatures shed from urban areas are between 2°C and 19°C greater than rural areas, depending on the time of day and ambient air temperature. Another study concluded that hot weather and elevated surface temperatures from impervious surfaces are the primary cause of thermal pollution (Wang et al., 2023).

Herb et al. (2007) simulated runoff heat transport through one-dimensional modeling for many surface types including asphalt, concrete, turf, bare soil, prairie grass, and corn crops and found that average runoff temperatures from impervious surfaces like commercial asphalt/gravel roofing and asphalt were about 3°C to 4°C higher than pervious surfaces like lawns and found that similar runoff temperatures were exported from the pervious surfaces regardless of surface type (e.g., lawn versus prairie). Simulated average runoff temperatures from bare soil were higher than pervious surface covers but lower than the impervious surface covers. Runoff temperatures spike following the initiation of runoff from heated surfaces and then tend to decrease toward an equilibrium temperature between the initial temperature of the surface cover and the rainfall (Herb et al., 2007; Thompson et al., 2008; LeBleu et al., 2019; Wang et al., 2023). This phenomenon is dependent on the heat transfer properties of the surface cover (Herb et al., 2007). Because pervious surfaces like sod tend to have lower surface temperatures compared to impervious surfaces, runoff transported from these surfaces tends to have lower average and peak temperatures. Some surfaces, like residential roofs, may have a low thermal mass that allows the surface to rapidly cool during rainfall, resulting in low average runoff temperatures (Herb et al., 2007).

WWE identified no physical or simulated studies on thermal pollution that have explored runoff shed from landscape surfaces such as pea gravel and wood mulch. However, these materials are common landscaping options for water-wise landscaping and turf conversions, and much is known about their function in landscaping and gardening. Surface temperatures from pea gravel tend to be lower than wood mulch and paved surfaces (Whiting et al., 2023), whereas gravels transfer more heat to the underlying soil than wood mulches (Klett, 2020). As previously established, surface temperatures impact average runoff temperatures from surface covers; however, thermal mass is also a critical component to average runoff temperatures. Higher temperatures in underlying soils may imply that gravel has a higher thermal mass when compared to wood mulches. Other confounding factors include the tendency for wood mulches exposed to high temperatures to become hydrophobic and for pea gravel to increase the infiltration rate of soils (Klett, 2020; Whiting et al., 2023).

The following conclusions can be drawn from the literature review presented above for thermal effects of landscape cover:

- Vegetation is consistently better at reducing runoff thermal pollution loading compared to impervious landscape surfaces, bare soil, and other permeable surface covers like mulch.
- Vegetated surfaces tend to have lower surface temperatures compared to other surface types, which decreases average runoff temperatures.
- Runoff temperatures are affected by both the initial temperature of the surface cover as well as other surface characteristics.
- Refined studies for runoff temperature responses from landscape surface types like wood mulch and gravels are not readily available. The ability of a surface cover to mitigate thermal pollution would benefit from additional monitoring and is included in forthcoming CWCB-sponsored research (Bhaskar, 2024).

5.0 HYDROLOGIC EFFECTS OF TURF CONVERSION

While the benefits of turf conversion for reducing the consumption of irrigation water are well documented (BBC, 2024), the effects of turf conversion on the rainfall-runoff response must also be considered when evaluating holistic environmental effects of landscape conversions. As discussed in Section 2, turf conversion projects can result in a variety of land cover types from highly impervious land cover such as hardscaping or compacted gravel, to highly pervious land cover such as native grasses or native and water-wise shrub, grass, and perennial plantings. In addition, details of how the alternative landscape is constructed such as the depth of topsoil or gravel, the use of weed barrier, effects of compaction during construction (Pitt 2012; Gregory et al. 2006), and provision of adequate irrigation can have significant effects on how much stormwater runoff a landscape will generate. This consideration is especially important in areas where existing storm drainage infrastructure is not sized to convey excess runoff generated by some types of turf conversion projects, which could create or exacerbate existing flood conditions. In other words, increases in runoff rates and volumes are considered negative effects of some types of turf conversions that result in greater imperviousness.

In 2022 and 2023, WWE worked for the MHFD and the City of Aurora to evaluate anticipated runoff characteristics of various land cover alternatives relative to irrigated turf. This work included a literature review and calculations to estimate the effective imperviousness of various land cover types that may be used for new development or for conversion of existing irrigated turf to various land covers used in water-wise landscapes. For this white paper, WWE's analysis estimates changes to anticipated runoff for various areas of Colorado for various levels of turf conversion and landscape cover types, building on prior work. Relative to other literature-review based sections in this white paper, the analysis and documentation is more detailed since it includes new original analysis, followed by simplified overall conclusions in Section 5.4.

5.1 Literature on Rainfall-runoff Relationships for Various Types of Water-wise Landscaping

There is a paucity of peer-reviewed literature evaluating the rainfall-runoff behavior of water-wise landscaping practices. The few papers that have evaluated this topic observed that artificial turf and Xeriscaping had substantially greater runoff rates and lower infiltration than irrigated grass turf (Simpson and Francis, 2021; Chang et al., 2021).

The Natural Resource Conservation Service's (NRCS's) Technical Release 55 Urban Hydrology for Small Watersheds (NRCS, 1986, referred to as TR-55) provides guidance on Curve Number (CN) runoff parameters for land uses including "pasture, grassland, or range" and for "western desert urban areas" including pervious "natural desert landscaping" and "artificial desert landscaping (impervious weed barrier)." The CN values recommended by TR-55 for various hydrologic soil groups and cover conditions are provided in Table 8 and were used in calculations to estimate runoff coefficients and the imperviousness of native grasses and desert landscaping.[4] Higher CNs indicate greater runoff.

[4] Curve numbers (CNs) and runoff coefficients are two ways to express how much rainfall becomes runoff. CNs are commonly used in less developed areas but have also been written into many urban

Table 8. CNs from TR-55 for Native Vegetation and Western Desert Xeriscaping Land Cover Types

Cover Type and Hydrologic Condition	Curve Numbers (CNs) for Hydrologic Soil Groups			
	A	B	C	D
TR-55 Land uses representing native vegetation				
Pasture, grassland, or range, lightly or occasionally grazed	39	61	74	80
Meadow, continuous grass, protected from grazing	30	58	71	78
TR-55 Land uses representing western desert Xeriscaping				
Natural desert landscaping (pervious areas only)	63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)	96	96	96	96

To understand how regions with semi-arid and arid climates manage water-wise landscaping in drainage planning, WWE conducted a review of various drainage criteria manuals in the southwestern United States. The City of Albuquerque, New Mexico, for example, assigns CNs to various land treatments, which describe how the land is used and its surface characteristics. CNs between 77 and 86 are assigned to native grasses, weeds, and shrubs, depending on factors like ground disturbance, slope, and soil type. For desert landscaping with gravel, a CN of 86 is assigned, which is similar to the NRCS TR-55 CN values for clayey soils.

In Arizona, Maricopa County's Drainage Design Manual distinguishes between desert landscaping with impervious layers underneath (e.g., weed barrier) (runoff coefficients ranging from 0.55 to 0.95) and no impervious layers underneath (runoff coefficients ranging from 0.3 to 0.5. Similarly, the criteria in Scottsdale, Arizona, use runoff coefficients of 0.37 to 0.45 for desert landscaping without a weed barrier and 0.63 to 0.83 when a weed barrier is present. In the City of Hurricane Utah's Drainage Manual, runoff coefficients for desert shrubs range from 0.01 to 0.2 depending on the amount of vegetation covering the land.

Drainage criteria in semi-arid and arid regions tend to assign higher CNs or runoff coefficients for desert landscaping with a weed barrier, while lower values are specified for areas with native grasses and shrubs. There is limited research on runoff coefficients for artificial turf and no known published runoff coefficients in other regional drainage criteria manuals.

5.2 Runoff Characteristics of Various Water-wise Landscaping Alternatives

Because of the scarcity of literature on rainfall-runoff characteristics of water-wise landscaping, WWE performed analysis to estimate the effective imperviousness of different types of water-wise landscaping. Imperviousness is a critical parameter for representing rainfall-runoff because it is used to determine a runoff coefficient for hydrologic analysis, in conjunction with the

drainage criteria manuals. In most of Colorado, runoff coefficients, ranging between 0.0 and 1.0 to represent the fraction of runoff, are used instead of CNs.

hydrologic soil group (a classification of soil infiltration and runoff potential) and the design storm return period. In addition, imperviousness is a direct input into the Colorado Urban Hydrograph Procedure (CUHP), which is used to model runoff hydrographs for designing stormwater infrastructure (MHFD, 2024). The discussion below provides WWE's analysis of runoff characteristics for various landscape types that could be used as alternatives to traditional irrigated turfgrass.

5.2.1 Native Grasses

Installing native grasses is a practical solution for replacing nonfunctional irrigated turfgrass. Northern Water (2024) estimates that warm-season native grasses have the potential to use 50 percent to 80 percent less supplemental irrigation compared to well-watered, cool-season grass like Kentucky Bluegrass, depending on factors such as irrigation efficiency, mowing frequency and weather. Photo 9 illustrates native grass landscaping. Establishing native grasses such as blue grama or buffalograss may require several years, depending on soil conditions and climate. The density of native grasses also varies between species, where some naturally grow low and clump together while others have more spreading growth and form denser stands. For native grasses, WWE evaluated several sources of information including current recommendations for imperviousness of lawns from the MHFD Storm Drainage Criteria Manual and City of Aurora Storm Drainage Design and Technical Criteria Manual, which range from 2 to 5% depending on soil type, and information from TR-55 related to pasture/rangeland. Because native vegetation is not typically irrigated (or irrigated at a much lower rate), these areas do not typically achieve the same density as irrigated cool season turfgrass, and if they do, it may take years to achieve such a density. Therefore, it makes sense that imperviousness values and runoff coefficients from areas planted with native grasses would be somewhat higher than for lawns. This is further explained below.

WWE used CNs from TR-55 for pasture/rangeland in good condition and meadows and performed the same calculations described above to estimate volumetric runoff coefficients and imperviousness. For a meadow (CN = 71), the resulting imperviousness was approximately 7%, and for pasture/rangeland in good condition (CN = 74), the calculated imperviousness was approximately 10%. The primary difference between pasture/rangeland in good condition and meadow is that the pasture/rangeland classification includes light or occasional grazing, which may also be representative of lesser vegetative densities during early years of establishment. These results are consistent with the observation that the imperviousness of native grasses should be somewhat higher than lawns. This is due to differences in vegetation density. If native grasses can be established with a density comparable to irrigated turf, the native grasses would produce somewhat less runoff than the irrigated turf due to the deeper roots of the native plants and the initial moisture that may be present in the soil with irrigated turf. However, in areas that are disturbed and then revegetated with native grasses (such as turf conversion projects), the native grasses typically do not have the same density as the irrigated turf they are replacing.

Photo 9. Native Grasses in a Denver suburb.

5.2.2 Xeriscaping with Wood Mulch

There is very little data on runoff from areas with wood mulch landscaping. A typical example is shown in Photo 10. Relative to western desert landscaping using gravel, landscaping with wood mulch has a greater capacity to absorb and hold water, and therefore should have a somewhat lower runoff coefficient and imperviousness. To evaluate Xeriscaping with wood mulch, WWE performed several calculations:

1. WWE applied regression equations developed by Chang et al. (2021) for wood mulch Xeriscaping. While these regression equations provided some insight, they were developed from data collected in Texas, which has significantly different climate and soil characteristics than Colorado. These equations were of limited utility in Colorado.

2. WWE performed initial and constant loss calculations, assuming a depression storage value of 0.2 inches (somewhat lower than the 0.35 inches of depression storage typically used for lawns, but at the low end of the published range) and a saturated soil hydraulic conductivity representative of hydrologic soil group C soils (typical of soils in Colorado in general and compacted urban soils in particular). These calculations were used to calculate volumetric runoff coefficients from which imperviousness was estimated from Table 6-5 in the MHFD Storm Drainage Criteria Manual.

Results of those calculations indicate an impervious value of 35% for wood mulch Xeriscaping without a weed barrier. The imperviousness for an installation with a weed barrier would be greater than 35% depending on the depth of the weed barrier, depth and porosity of material above the weed barrier, holes in the weed barrier for plantings, and effects of vegetation.

Photo 10. Xeriscaping with Wood Mulch.

5.2.3 Xeriscaping with Gravel Mulch (Western Desert Landscaping)

Western desert landscaping typically consists of gravel or rock mulch with xeric plantings. Western desert landscaping is often installed with a weed barrier, which can have dramatic effects on runoff characteristics if it is shallow. Weed barriers also become less permeable over time. An example of western desert landscaping is shown in Photo 11. Because runoff coefficients in the MHFD are determined based on imperviousness, WWE performed the following procedure to estimate runoff coefficients and imperviousness based on CNs from TR-55:

1. Calculate the volume of runoff for 24-hour precipitation depth using NRCS CNs to compute losses and the volume of runoff for 2-, 5-, 10-, 25-, 50-, and 100-year events.

2. Calculate the volumetric runoff coefficient by dividing the volume of runoff from the CN calculation by the total 24-hour precipitation depth.

3. Look up imperviousness values corresponding to calculated runoff coefficients for each return period using Table 6-5 from the Runoff Chapter of the MHFD Urban Storm Drainage Criteria Manual (MHFD, 2024).

4. Average imperviousness values were used to determine representative imperviousness for land use.

These calculations were performed for hydrologic soil group C because these soils are predominant along the Front Range of Colorado.

Based on this analysis, a CN of 85 (for natural desert landscaping, pervious areas only with no weed barrier), hydrologic soil group C) would correspond to volumetric runoff coefficients ranging from 0.36 for the 2-year event to 0.68 for the 100-year event and an average imperviousness of 46%. As a point of reference, stormwater criteria for Arizona's Maricopa County use runoff coefficients for desert landscaping without imperviousness ranging from 0.3 to 0.5, so the value calculated using this method falls within the published range in Maricopa County.

Photo 11. Western Desert Landscaping (Gravel Mulch).

For the case with a weed barrier, the NRCS CN is 96 for all hydrologic soil groups, reflecting the impermeable nature of the weed barrier. For hydrologic soil group C, a CN of 96 corresponds to volumetric runoff coefficients ranging from 0.76 for the 2-year event to 0.91 for the 100-year event and an average imperviousness of 97%. As a point of reference, stormwater criteria for Maricopa County use runoff coefficients for desert landscaping with impervious treatment ranging from 0.55 to 0.95, similar to the range calculated by WWE but slightly lower. The slightly lower values in the Scottsdale criteria are likely due to somewhat lower precipitation depths compared to the Denver Metropolitan area. Converting the CNs for western desert landscaping with weed barrier results in fairly high runoff coefficients and imperviousness, as would be expected for a CN of 96. However, the TR-55 guidance does not specify the depth of the weed barrier and does not account for effects of vegetation or holes in the weed barrier for planting containerized plants. All of these factors would tend to lower CN values and runoff coefficients and may be more representative of landscaping practices along the Front Range. In addition, native plants and shrubs on the semi-arid Front Range of Colorado have different characteristics and greater density of cover than native plants in arid climates. When appropriate plants are used in conjunction with gravel or wood mulch Xeriscaping in Colorado, the density of vegetation typically would be greater than in the arid southwest. Therefore, WWE believes that the estimates of imperviousness for western desert landscaping derived from TR-55 CNs tend to be on the high side. Nonetheless, this type of landscaping would be expected to produce more runoff than irrigated turf or native grasses, which provide more depression storage and infiltration.

5.2.4 Artificial Turf

An example of artificial turf is shown in Photo 12. Artificial turf is made to be porous and allow water to infiltrate through to the underlying soil. Compared to traditional turfgrass lawns, artificial turf produces greater runoff volumes (Simpson and Francis, 2021; Chang et al., 2021), but less cumulative runoff compared to Xeriscaping (Chang et al., 2021). Therefore, the runoff coefficient for artificial turf should be greater than the value for traditional lawns but lower than for Xeriscaping practices.

Photo 12. Artificial Turf.

To evaluate artificial turf, WWE performed several calculations, similar to the evaluation for Xeriscaping with wood mulch:

1. WWE applied regression equations developed by Chang et al. (2021) for artificial turf.[5] A caveat is that these regression equations were based on data collected in a significantly different climate and soil characteristics.

2. WWE performed initial and constant loss calculations as described above. These calculations were used to calculate volumetric runoff coefficients from which imperviousness was estimated from Table 6-5 in the MHFD Storm Drainage Criteria Manual.

---

[5] Chang et al. (2021) developed quadratic regression equations for artificial turf, wood mulch Xeriscape, gravel mulch Xeriscape, and St. Augustine grass lawns with two years of continuous rainfall and runoff data. Data were collected for 24 individually irrigated 4.1-m by 8.2-m plots.

According to the Synthetic Turf Council, the standard for water permeability is a minimum rate of 10 inches of water per hour, but some turf types can drain up to 30 inches per hour. A manufacturer, En-Plast, specifies a runoff coefficient of 0.4 for their product according to their Drainage Capacity and Time to Drain Design Manual (En-Plast, 2021). Many manufacturers note that artificial turf should be installed with an adequate permeable subgrade with well drained material or an underdrain system.

The calculations performed by WWE and the point of reference from En-Plast indicate that the runoff coefficient for artificial turf ranges between 0.2 to 0.7. Based on this information and the analysis, an imperviousness between 25% and 45% for residential and commercial applications is considered reasonable. A higher imperviousness between 60% and 80% is appropriate for large sport turf fields where an underdrain system is incorporated, as most of the water infiltrating at a high rate through the turf would be captured in the underdrain system and conveyed directly to a storm drain.

Western Resource Advocates: "Is Artificial Turf a Beneficial Water Conservation Tool in the West?"

In 2022, Western Resource Advocates prepared a paper title "Is Artificial Turf a Beneficial Water Conservation Tool in the West?" (Benjamin, 2022). WRA noted that artificial turf conserves water used on outdoor landscapes and sports fields and eliminates the need for pesticides, herbicides, and fertilizers. However, tradeoffs identified by WRA included chemicals and microplastic particles that make up artificial turf that can leach into the environment, without fully characterized environmental and health impacts. WRA identified several other considerable drawbacks such as unexpected negative impacts to water supplies including requiring watering for cooling on hot days and hindering groundwater recharge. Additionally, the heat generated by artificial turf can increase urban heat island effect and cause heat-related injuries. Other concerns identified included limited recycling options.

5.3 Analysis and Discussion

A wide variety of water-wise landscaping practices with varying imperviousness can be used for turf conversion efforts. Table 9 presents conceptual imperviousness values and runoff coefficients representative of a range of turf conversion alternatives from native grasses to hardscape. Note that the values in this table are approximate values based on the literature review and the calculations described above. In reality, significant variability in these values may exist depending on installation, maintenance, and other site-specific factors. The volumetric runoff coefficients, which represent the fraction of rainfall that becomes runoff, are based on guidance from MHFD for runoff coefficients for the water quality event for Hydrologic Soil Group C soils, which are predominant in most upland areas along the Front Range.

Table 9. Spectrum of Land Cover Types, Representative Imperviousness, and Volumetric Runoff Coefficients

Land Cover Type	Representative Imperviousness (%)	Volumetric Runoff Coefficient*
Undisturbed Native Vegetation	5	0.03
Irrigated Turf, Decompacted Soils	8	0.05
Restored Native Vegetation, Decompacted Soils	10	0.06
Irrigated Turf, Compacted Soils	20	0.14
ColoradoScaping, Wood Mulch with 50% Plant Coverage	23	0.16
Wood Mulch, 20% Plant Coverage	30	0.22
Gravel Mulch, 20% Plant Coverage	34	0.25
Artificial Turf, no underdrain	35	0.26
Gravel Mulch, Uncompacted, Pedestrian Use Only	40	0.30
Artificial Turf, with Underdrain	70	0.56
Gravel Mulch, Shallow Weed Barrier	90	0.74
Hardscaping	100	0.83

* Assumes NRCS Hydrologic Soil Group C, which is common in many locations in Colorado and also representative of many urban soils.

To evaluate how these volumetric runoff coefficients translate into runoff, WWE performed rainfall-runoff calculations for a range of turf conversion scenarios using long-term rainfall time series representative of the Denver metropolitan area, the Northern Front Range (Larimer and Weld Counties), the Southern Front Range (El Paso and Pueblo Counties), and the Western Slope. The regions selected for the analysis correspond to the areas for which data on irrigated turf acreage are presented in the BBC (2024) report for CWCB. Table 10 summarizes Irrigated turf acreage for each of these regions.

Table 10. Irrigated Turf Acreage in Colorado (Source: BBC, 2024)

Regional Irrigated Turf Acreage using Municipal Supply	Approx. Area (acres)
DRCOG Region	104,800
North Metro (Larimer & Weld Counties)	21,000
South Front Range (El Paso & Pueblo Counties)	26,700
Non-Front Range (Grand Junction, Durango, others)	15,300
Total	167,800

WWE evaluated scenarios with 25%, 50%, and 75% of the irrigated turf areas in Table 10 converted to water-wise land uses. To span the spectrum of water-wise practices, WWE evaluated three land use scenarios representing a mix of the landscape types in Table 9:

1. **Native Grasses and Plantings**
   This scenario assumes:
   - 50% of the area is replaced with native turf-forming grasses
   - 50% is replaced with ColoradoScaping with 50% plant coverage and 50% wood mulch

   The composite runoff coefficient for this scenario was **0.11**.

2. **Mulch with Limited Vegetation**
   This scenario assumes:
   - 60% of the area replaced with wood mulch with at least 20% vegetative cover
   - 30% of the area replaced with gravel mulch with at least 20% vegetative cover
   - 8% of the area replaced with gravel mulch with no vegetation
   - 2% of the area replaced with artificial turf, without an underdrain system

   The composite runoff coefficient for this scenario was **0.23**.

3. **Mulch with Limited Vegetation and Some Hardscape**
   This scenario assumes:
   - 35% of the area replaced with wood mulch with at least 20% vegetative cover
   - 35% of the area replaced with gravel mulch with at least 20% vegetative cover
   - 10% of the area replaced with gravel mulch with no vegetation and shallow weed barrier
   - 10% of the area replaced with hardscape
   - 8% of the area replaced with gravel mulch with no vegetation
   - 2% of the area replaced with artificial turf, without an underdrain system

   The composite runoff coefficient for this scenario was **0.36**.

WWE also evaluated a status quo scenario with no changes in irrigated turf to provide a baseline from which to gauge changes. The status quo scenario has a composite runoff coefficient of **0.11** (note, this is the same runoff coefficient as the "Native Grasses and Plantings" scenario). WWE used representative long-term daily precipitation data for each of the regions in Table 10 to calculate runoff on a daily time step, excluding precipitation events with depths of less than 0.08 inches, which would not be expected to generate runoff. WWE used precipitation data from Fort Collins to represent the northern Front Range (Larimer and Weld counties), data from Colorado Springs to represent the southern Front Range (El Paso and Pueblo counties), and data from Grand Junction to represent the west slope for purposes of this highly conceptual analysis. Figure 5 and Table 11 present the results of these calculations.

Figure 5. Average Annual Runoff by Turf Conversion Scenario and Amount of Turf Converted for each Region
(Calculations Based on Daily Precipitation Data from 1990 through 2022.)

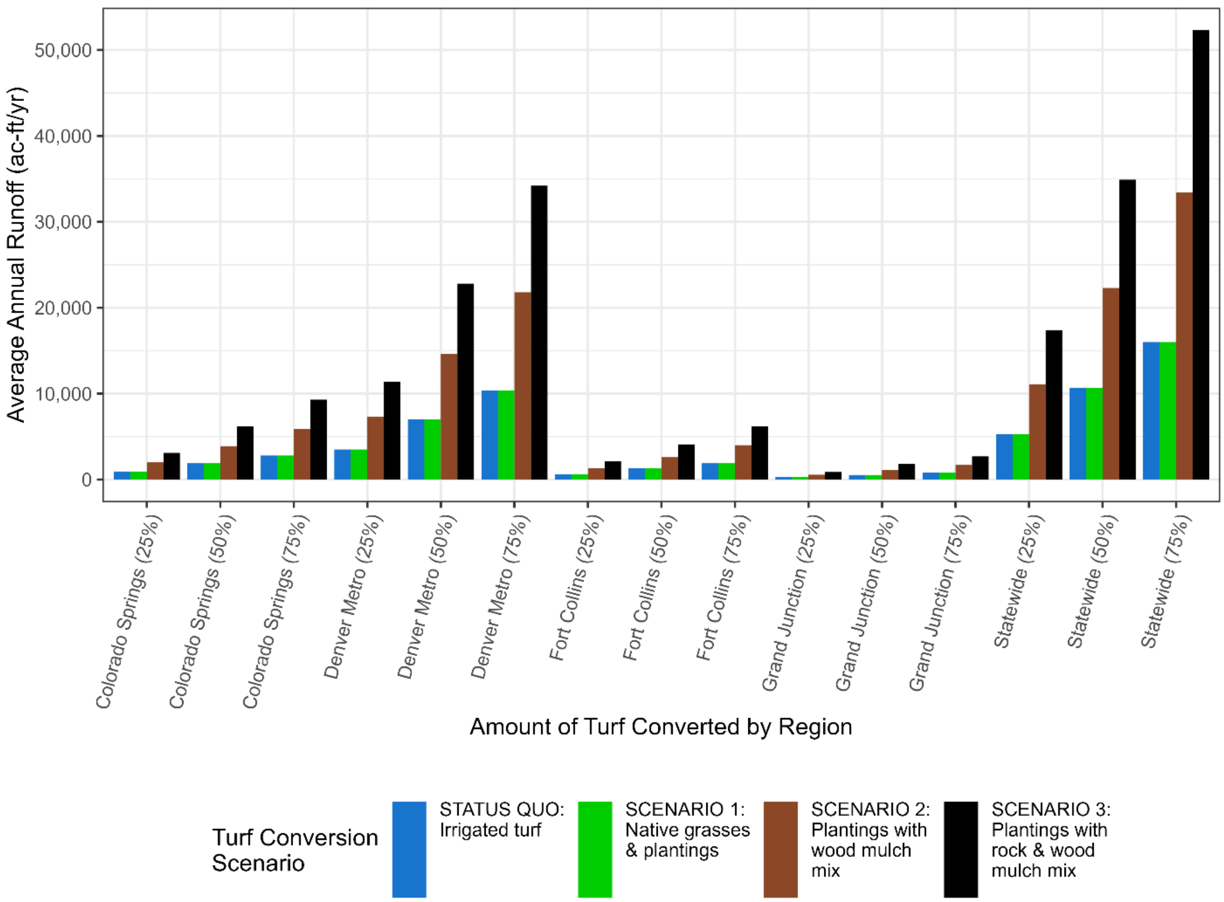


Table 11. Volume of Average Annual Runoff Produced by Turf Conversion Scenarios Relative to Irrigated Turf Baseline Condition

Amount of Turf Converted by Region	Modeled Average Annual Runoff (ac-ft/yr) from 1990 – 2022 for Turf Conversion Scenarios			
	STATUS QUO **Irrigated Turf**	SCENARIO 1 **Native Grasses & Plantings** *(0% difference from Status Quo)*	SCENARIO 2 **Plantings with Wood Mulch Mix** *(110% more runoff than Status Quo)*	SCENARIO 3 **Plantings with Rock and Wood Mulch Mix** *(225% more runoff than Status Quo)*
Denver Metropolitan				
25% (26,200 ac)	3,500	3,500	7,300	11,400
50% (52,400 ac)	7,000	7,000	14,600	22,800
75% (78,600 ac)	10,400	10,400	21,800	34,200
Northern Front Range				
25% (5,255 ac)	630	630	1,300	2,100
50% (10,509 ac)	1,300	1,300	2,600	4,100
75% (15,764 ac)	1,900	1,900	4,000	6,200
Southern Front Range				
25% (6,670 ac)	940	940	2,000	3,100
50% (13,341 ac)	1,900	1,900	3,900	6,200
75% (20,011 ac)	2,800	2,800	5,900	9,300
West Slope				
25% (3,825 ac)	270	270	560	880
50% (7,650 ac)	540	540	1,100	1,800
75% (11,475 ac)	810	810	1,700	2,700
Statewide				
25% (41,950 ac)	5,300	5,300	11,100	17,400
50% (83,900 ac)	10,700	10,700	22,300	34,900
75% (128,850 ac)	16,000	16,000	33,400	52,300

These results show that the type of landscape that replaces irrigated turf is very important in terms of hydrologic effects. For projects that replace irrigated turf with turf-forming native grasses and other dense vegetative cover, such as Scenario 1: Native Grasses & Plantings in Table 11, changes to rainfall-runoff can be minimized and even reduced in some cases. However, unless significant vegetative components are integrated into the landscape, practices that rely on mulch with less vegetative cover have the potential to increase stormwater runoff, and practices that employ shallow weed barriers and/or hardscaping can substantially increase stormwater runoff. Furthermore, for each alternative landscape scenario evaluated, WWE assumed proper landscape installation practices and good maintenance practices. Poor installation and/or maintenance of vegetation, mulch, and other components of the landscape would lead to even greater runoff.

Results in Table 11 are presented in terms of acre-feet to illustrate the magnitude of these changes across broad geographic areas of the state. In terms of urban hydrology, peak flow rates are often of greater concern than runoff volume because the peak flow rate dictates sizing of conveyance systems such as swales, storm drains, and open channels. While turf conversions that establish dense stands of native, turf-forming grasses are unlikely to result in significant hydrologic changes in terms of volume or peak rate of runoff, those that rely heavily on wood or gravel mulch with fewer plants and projects that introduce compacted gravel or crusher fines areas for pedestrian use have the potential to increase the volume and peak rate of runoff.

Fortunately, turf conversion opportunities are often spread across large watersheds, comprising a small fraction of the total drainage area. However, if larger scale turf conversion projects are implemented at institutional (e.g., campus) or commercial sites or on a neighborhood scale, potential increases in peak runoff rates should be evaluated to verify that existing stormwater conveyance systems have capacity to accommodate the changes without increasing flood risk. Based on runoff coefficients, the peak flow rate for Scenario 2 (Plantings with Wood Mulch Mix) would be approximately double that of irrigated turf or Scenario 1 (Native Grasses & Plantings). The peak flow rate for Scenario 3 (Plantings with Rock & Wood Mulch Mix) would be roughly triple the peak flow rate for irrigated turf or Scenario 1.

Based on this analysis, it is clear that the choice of landscape that replaces irrigated turf has significant implications for rainfall and runoff that cannot be ignored unless practices that reestablish a dense vegetative cover are used. In areas that are already developed and served by storm drainage systems that cannot easily be upsized, it may be prudent to regulate the types of turf conversions allowed to avoid exacerbating existing flooding issues or creating new ones. CWCB's Turf Replacement Grant Program Guidelines (2024) currently target a minimum of 50% replacement vegetation at maturity. It is noteworthy that another factor with potential to increase the rate and volume of runoff is redevelopment that results in densification of development on a lot. When a lot redevelops and the footprint of impervious area increases, this is effectively converting land that was previously pervious (to at least some degree) to an impervious surface. On such lots, the quality of the remaining receiving pervious areas should be protected (e.g., healthy soil and vegetation conditions).

Based on water-wise landscaping practices analyzed above and summarized in Table 11, which are only points on the spectrum of potential alternatives, imperviousness of different pervious landscaping practices could range from 5 to 40% and even higher when a weed barrier is used with shallow layer of soil or gravel or for hardscaping. Conceptually understanding how the various turf conversion alternatives in Table 11 would be expected to affect generation of stormwater runoff is an important hydrologic consideration in selecting an alternative to replace irrigated turf.

Application of Imperviousness Values in Drainage Criteria Manuals

Because of the wide range of imperviousness values for water-wise landscaping based on the literature and calculations and the lack of regional data, MHFD and City of Aurora opted to use a representative value of 20% to represent "Disturbed Soil (Including Lawns, Managed/Active Turf, Landscaped Areas with Water-Wise Vegetation, and Uncompacted Gravel/Mulch Planting Beds)" (MHFD, 2024). The reasons for using representative values instead of establishing imperviousness criteria for the specific land cover types presented in Table 9 (wood mulch versus gravel mulch versus native grasses) included:

- The landscaping planned when a development is originally constructed may not be the landscaping present in the future. Homeowners often customize landscaping to their preferences. Turf conversions are a good example of the dynamic nature of landscape changes.

- Drainage infrastructure is constructed as an area is developed but must serve its function over a multi-decade design life, during which there will undoubtedly be landscape changes. The representative imperviousness value of 20% is a balance between some types of landscaping that enable more infiltration (dense native grasses) and those that may have more limited infiltration (gravel mulch with limited plantings).

As a point of comparison, the imperviousness for "Undisturbed or Decompacted Soil (Native Grasses and Open Space Areas)" is 5%. Comparison of this with the 20% used for landscaping following soil disturbance highlights the significant effects of compaction during construction on soil infiltration rates (Gregory et al., 2006, Pitt, 2012). While this approach makes sense from the perspective of drainage criteria, which must often strike a balance between granularity and practical application, consideration of expected imperviousness is an important hydrologic consideration in selecting an alternative to replace irrigated turf.

5.4 Summary of Findings for Rainfall-Runoff Analysis

The overall conclusion of WWE's hydrologic analysis is that turf conversion projects have the potential to increase imperviousness and runoff relative to irrigated turf, depending on the type of landscape that replaces the irrigated turf. In some cases, rainfall-runoff characteristics may not change significantly when turf is replaced with vegetated landscapes that have adequate depth of soil/media. However, alternative landscapes that have few plants, and especially those that incorporate weed barriers at shallow depths, are likely to produce more runoff than the irrigated turf surfaces they are replacing. This can lead to increases in the rate and volume of stormwater runoff that must be considered in the context of the available capacity of the storm drainage system serving the site. Because individual property owners are typically not aware of relationship between land surface, stormwater runoff and capacity of the existing drainage system, local governments and water providers may want to consider how turf removal programs are targeted within their communities, considering both water conservation and storm drainage objectives/limitations. Additionally, turf replacement programs that maintain pervious surfaces with living landscapes generally maximize both objectives.

6.0 URBAN HEAT ISLAND EFFECTS OF TURF CONVERSION (AIR TEMPERATURE)

Urbanization, with increased heat-retaining impervious surfaces, has well documented “urban heat island effects” (USEPA, 2008). Johnson et al. (2017) summarizes some of these effects and the role that landscaping plays in mitigating these effects:

- *When there is limited vegetation in a community, buildings and paved surfaces absorb energy from the sun and cause the surface temperature of urban structures to be 18 to 38°F higher than the ambient air temperatures (Taha et al., 1992). Higher air temperatures lead to increased need for cooling systems, straining natural resources required to cool our homes and businesses.*

- *Unlike paved areas which absorb solar radiation, vegetation cools the air when moisture evaporates from soil and plants. Landscaping, specifically trees, can also reduce home energy costs for heating and cooling. Three trees properly placed around the home can save $100 to $250 annually in energy costs (USDOE, 2003).*

- *Additionally, shade from trees significantly mitigates the urban heat island effect (USEPA, 2016). Tree canopies provide surface temperature reductions on wall and roof surfaces of buildings ranging from 20 to 45° F and temperatures inside parked cars can be reduced by 45°F (Akbari et al., 1997).*

> Many urban and suburban **Urban Heat Islands**
> (USEPA, 2008)
>
> areas experience elevated temperatures compared to their outlying rural surroundings; this difference in temperature is what constitutes an urban heat island. The annual mean air temperature of a city with one million or more people can be 1.8 to 5.4°F (1 to 3°C) warmer than its surroundings, and on a clear, calm night, this temperature difference can be as much as 22°F (12°C). Even smaller cities and towns will produce heat islands, though the effect often decreases as city size decreases.

EPA (2024) also notes that trees and vegetation (e.g., bushes, shrubs, and tall grasses) lower surface and air temperatures by providing shade and cooling through evaporation and transpiration. Trees and vegetation also provide cooling through evaporation of rainfall collecting on leaves and soil. Research shows that urban forests have temperatures that are on average 2.9°F lower than unforested urban areas (Knight et al., 2021). NASA identified the presence of vegetation as an essential factor in limiting urban heating and further noted that the amount and type of vegetation plays a big role in how much urbanization changes the temperature (Gray, 2015).

When turf-based landscapes are removed to meet water conservation objectives, it is important to consider what turf landscapes are converted to and the environmental effects of the alternative landscape—heat island effects are an important consideration. Generally speaking, landscapes that provide evapotranspiration and shade reduce heat, whereas hard surfaces such as concrete and gravel increase temperatures. The magnitude of heat increases when transitioning from turf landscapes to other landscapes with less-intensive irrigation requirements depends on factors such as aspect, tree canopy, evapotranspiration associated with the replacement plant palette, actual irrigation practices and the degree to which hardscape is integrated into the new landscape.

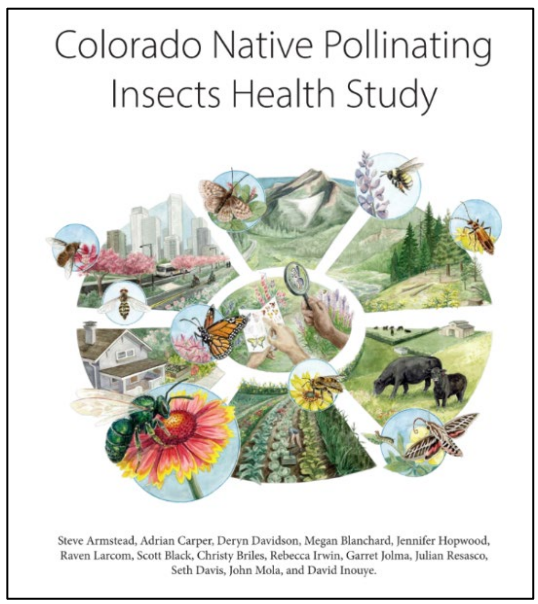
Properties of urban materials, in particular solar reflectance, thermal emissivity, and heat capacity, also influence urban heat island development, as they determine how the sun's energy is reflected, emitted, and absorbed (USEPA, 2008). Generally, replacing turf with other living landscapes will result in the least increase in urban heat island effects.

An additional consideration related to the need to maintain living landscapes in turf replacement projects is that development continues to occur in Colorado, reducing green space. For example, land use changes averaged around 10 percent from 2001 to 2021 in Denver, Arapahoe and Douglas counties, based on analysis in the EVA Tool (mrlc.gov). Loss of grassland to urbanization compounded with removal of turf areas to meet water conservation objectives could exacerbate heat island effects if turf removal and turf ordinances do not require that these areas be replaced with living landscapes (i.e., vegetation and mulch selections that minimize heat effects).

As an overall conclusion, unintended heat island effects of turf conversions can be minimized by selecting living landscapes and incorporating tree canopy. When turf conversions occur in areas with existing trees, it is essential to maintain adequate irrigation to meet the water requirements of the trees.

7.0 POLLINATOR EFFECTS OF TURF CONVERSIONS

In response to Senate Bill 22-199, the Colorado Department of Natural Resources (DNR) commissioned a study on native pollinating insects. This collaborative study was conducted by Colorado State University Extension, the Xerces Society for Invertebrate Conservation, and the University of Colorado Museum of Natural History, in consultation with state and federal agencies, researchers, scientists, and land managers across the state. For more information, see Native Pollinating Insects Health Study | Department of Natural Resources (DNR) (colorado.gov). The DNR study found that the greatest opportunity for improving the health of native pollinating species and their habitats is through the replacement of harmful human practices with beneficial ones in agricultural and urban places (Armstead et al, 2024). The priorities for pollinating insect health and management identified in the DNR report include:



1) Protect imperiled native pollinating insects.

2) Protect, restore, and connect pollinator habitats.

3) Mitigate environmental changes that negatively impact pollinators and their habitats.

4) Reduce the risks from pesticides to pollinating insects.

5) Monitor and support native and managed pollinator health.

In another recent study, the Salazar Center for North American Conservation at Colorado State University and Denver Parks and Recreation completed a 2024 report "Optimizing Plant Choices to Maximize Pollinator Habitat, Climate Resilience, and Social Values across Denver Parks and Neighborhoods." The report identifies the need for creation of pollinator-friendly habitat within urban environments and a need to increase the connection that urban residents feel with natural spaces. The study included three stated broad objectives:

> 1) To understand the existing pollinator biodiversity across Denver Parks and how it relates to local and landscape scale factors like floral species richness within parks and urbanization and economic factors surrounding parks;
>
> 2) to describe the values and perspectives of Denver residents towards pollinator-friendly landscaping and understand how to improve the favorability of landscaping elements associated with native plant restoration; and
>
> 3) to provide guidance on pollinator-friendly plant mix design for Denver Parks and Recreation with respect to climatic factors like drought tolerance as well as their potential attractiveness to pollinators.

Findings from this report may serve as a resource for identifying plants for turf-replacement projects that have the added co-benefit of providing pollinator habitat.

As another example of the value of native grasses as low water landscaping alternatives that provide co-benefits of pollinator habitat, USDA notes these specific benefits (USDA, 2024):

- ***Habitat and Shelter****: Grasses provide essential habitat and shelter for pollinators. Their dense foliage and upright growth form create microhabitats where insects are protected from adverse weather conditions, predators, or disturbances. The clumps or bunches of grasses also offer nesting sites for ground-nesting bees and other insects.*

- ***Larval Host Plants****: Certain warm-season grasses serve as larval host plants for specific pollinator species. Butterflies lay their eggs on the grass, and the emerging caterpillars feed on the leaves. For example, little bluestem (Schizachyrium scoparium) is the larval host plant for several skipper species and big bluestem (Andropogon gerardii) and switchgrass (Panicum virgatum) are the caterpillar host plants for banded skippers and satyrs. By incorporating these grasses into landscapes, we provide crucial resources for the complete life cycles of these pollinators.*

- ***Connectivity and Corridors**: Warm-season grasses can create pollinator corridors and add connectivity between habitats. These grasses are often planted in large swaths or prairie restorations, forming a network of suitable foraging areas for pollinators. This interconnectedness helps pollinators find suitable resources, enhancing their foraging efficiency and genetic exchange.*

> **Resources for Creating Pollinator Habitat**
>
> Creating Pollinator Habitat- CSU Extension
>
> Resources to Help Pollinators | Natural Resources Conservation Service (usda.gov)

In terms of the range of turf replacement project alternatives, native plants and grasses will provide benefits to pollinators; however, replacement approaches such as rock and hardscape do not provide these benefits.

8.0 CARBON SEQUESTRATION CONSIDERATIONS FOR URBAN LANDSCAPES

Plants assimilate atmospheric carbon dioxide through photosynthesis and store carbon in plant biomass and soil. Wang et al. (2022) conducted a literature review to compare relative carbon sequestration benefits of various landscape types. Turfgrass systems were generally identified as carbon-neutral or carbon sinks, with the exception of intensively managed areas like golf courses and athletic fields. Other selected findings from sources compiled by Wang et al. (2022) include:

- Research by Qian and Follett (2002) concluded that carbon sequestration in turf soils occurs at a significant rate that is comparable to carbon sequestration for land in the Conservation Reserve Program in the U.S. This research was based primarily along the Colorado Front Range.

- Soil organic carbon for a woodchip mulched bed was similar to that of a lawn, based on a study in Victoria, Australia (Livesley et al. 2010).

- In arid climates, turfgrass is often reported to have higher soil organic carbon stocks than native vegetation, citing studies by Trammell et al. (2020), Golubiewski (2006), Kaye et al. (2005), and Pouyet et al. (2009).

- Several studies showed that lawns and grasslands had more soil organic carbon than bare soil (Acuna et al., 2017; Bae and Ryu, 2017, Upadhyay et al., 2021) or gravel (Byrne et al. 2008).

Wang et al. (2022) concluded that proper management practices are crucial for minimizing biotic and abiotic stresses in turfgrass which can cause respiration to exceed photosynthesis, resulting in CO_2 release into the atmosphere. In particular, irrigation, fertilization, and mowing practices can positively or negatively affect the ability of turfgrass systems to assimilate and store carbon. Hidden carbon costs (HCCs) and net Greenhouse Gas (GHG) emissions are considerations related to maintenance of turfgrass that can offset carbon sequestration by urban lawns, depending on how the lawn is managed.

For purposes of this white paper, carbon sequestration is an environmental consideration for turf landscape conversions. When turf replacement projects are undertaken, replacement of turf with other living landscapes is preferable to conditions such as hardscape, bare soil or gravel. The net carbon sequestration benefit of turfgrass to other vegetation varies depending on management practices and other factors.

9.0 COMMUNITY VALUES

From a social perspective, green spaces provide health and a range of recreational and psychological benefits, create environmental awareness and provide other benefits (Velasco et al. 2016). Although this white paper focuses primarily on environmental considerations of turf alternatives, community acceptance and consistency with community values are essential considerations for turf conversions and their long-term success. Community values can include but should not be limited to "water conservation only" approaches; instead, multiple community values (e.g., wellness, tree canopy, pollinator habitat, green space, play areas for kids and pets). should be considered in a holistic manner and planned concurrently.

Particularly in underserved communities with histories of abandoned landscape projects (Photo 13), buy-in from the community on larger scale turf conversion projects is important, along with a commitment and plan for long-term maintenance and social cues (e.g., signage) describing landscape conversion benefits.

As discussed in Section 7, the Salazar Center at CSU and Denver Parks and Recreation (2024) recently completed an in-depth study titled "Final Report for Optimizing Plant Choices to Maximize Pollinator Habitat, Climate Resilience, and Social Values across Denver Parks and Neighborhoods." This report is a source of more in-depth information related to social acceptance of landscape conversion projects. One high level conclusion from this report that relates to community values and landscape conversions include the importance of installing "cues of care" like benches, pathways, and interpretive signs to improve public acceptance of pollinator-friendly and native landscapes.

Further exploration of community values is beyond the scope of this white paper, but community values are real and important considerations when transforming landscapes in public spaces and neighborhood-scale programs, both in terms of initial transformation and long-term maintenance requirements.

Denver neighborhood split by I-70 to add more trees, murals, green space

Coalition breathing new life into long-abandoned landscape project, split in two by I-70, in Globeville

RiNo business owner Jevon Taylor and his dog Benny stand in front of an existing mural at the corner of North Lincoln Street and East 46th ave directly below I-70 in the Globeville neighborhood of Denver on Nov. 27, 2023. (Photo by Helen H. Richardson/The Denver Post)

Photo 13. "We just want nice things in our neighborhood…" Athony Garcia, Globeville resident in article by Judith Kohler, Denver Post, January 17, 2024. https://www.denverpost.com/2024/01/17/globeville-neighborhood-green-landscape-trees/

10.0 SUMMARY AND RECOMMENDATIONS REGARDING HOLISTIC ENVIRONMENTAL EFFECTS OF LANDSCAPE TRANSFORMATION PROJECTS

Turf replacement programs and incentives should consider holistic environmental benefits of turf conversion projects in a strategic manner that minimizes unintended environmental effects. To synthesize the multiple environmental effects of turf conversions presented in this white paper, WWE prepared Table 12 to represent a simplified reasonable range of turf transformation types to compare against traditional irrigated turf areas, including:

1. Turf conversion to native grasses.

2. Turf conversion to native and low-water plantings with wood mulch.

3. Turf conversion to gravel mulch Xeriscape with some plantings.

As a general summary, the holistic environmental benefits of non-functional turf conversion are greatest when turf is converted to other living landscapes as opposed to rock (gravel mulch) or hardscape replacements. When incentivizing turf conversion projects, CWCB and local governments may achieve multiple co-benefits ("benefit stacking") of such projects by considering additional environmental factors that go beyond water conservation such as heat island effects, carbon sequestration, pollinator benefits, and community values. There may be multiple benefits to collecting additional data to support the environmental effects of conversions to various landscape types.

The actual benefits of any turf conversion project are influenced by a variety of site-specific factors such as design, installation, long-term maintenance ability, and community acceptance. Continued sharing of successes and failures and refinement of best practices through collaborative efforts is needed. Additionally, the understanding of best practices for turf removal continues to evolve and may vary by project scale. For example, homeowners may be able to implement small-scale turf conversion projects with minimal to no herbicide use. For larger scale projects, current experience indicates that herbicide application is likely necessary. When used, herbicides should be applied following product labels and with appropriate PPE. Large-scale projects should use licensed pesticide-applicators to minimize potential adverse effects of herbicides.

Existing tree lawns typically include a combination of irrigated turf and trees. Given the multiple environmental and community benefits of trees, care should be taken to provide the irrigation needs of trees when turf conversion projects are undertaken.

Table 12. Effects of Turf Replacement Scenarios Relative to Traditional Irrigated Turf

Parameters	Expected Change Related to Type of Turf Replacement		
	Native Grasses	**Wood Mulch with Native Plantings Xeriscape**	**Gravel Mulch Desert Xeriscape**
Infiltration	Minimal change	Minimal change to slight decrease	Decrease
Runoff	Increase during establishment / minimal change once established	Increase during establishment / minimal change to slight increase once established	Increase
Evapotranspiration (ET) (proxy for water use)	Decrease	Decrease	Decrease
Nutrients in Runoff	Decrease*	Decrease*	Decrease
Herbicides in Runoff	Decrease (once established)	Site-specific	Site-specific
Runoff Temperature	Minimal change	Slight to moderate increase, depending on density of plants	Increase
Urban Heat Island (Air Temperature)	Minimal change	Slight to moderate increase, depending on density of plants	Increase
Pollinator Effects	Increase	Increase	Decrease
Carbon Sequestration	Site-specific/ Dependent on Management	Site-specific/ Dependent on Management	Decrease
Community Greenspace	Minimal change (if appropriate for expected uses)	Minimal change (if aesthetically designed with ample plantings)	Site-specific to Decrease

* = Expected decrease based on decrease in amount of fertilizer applied; however, further research is needed for better quantification and verification of benefits. Actual benefit depends on management practices.

In addition to the overarching conclusion provided above, this white paper provided new quantitative analysis related to hydrologic changes associated with turf conversions. Specific recommendation for this aspect of turf conversions include:

1. To minimize adverse impacts to hydrology (e.g., increased runoff), water quality, and urban heat island effects and provide the greatest overall environment benefits, turf conversion projects should maximize vegetative cover with plants appropriate for local conditions.

2. When turf conversions occur in areas with mature trees (e.g., tree lawns), irrigation of trees should continue to be provided due to the multiple benefits associated with trees (e.g., reducing heat stress, shade, other community benefits).

3. When replacing turf with native grasses, sod-forming (turf-like) native grasses are preferable to bunch grasses due to the greater ground cover, which slows sheet flow and minimizes erosion relative to types of plants that allow for preferential flow around the bases of plants.

4. Provide healthy topsoil appropriate for native vegetation and low-water shrubs. At a minimum, 6 inches of topsoil should be used, and in some jurisdictions, a minimum of 12 inches is required. This topsoil not only provides important growing media plants but also enables precipitation to infiltrate (e.g., sponge effect) on site, providing stormwater management benefits.

5. Be aware that weed barriers, particularly at shallow depths, can create a hydraulically restricted layer. Minimize use of weed barriers to the extent feasible to enable stormwater infiltration and reduce excess runoff.

6. Plan for temporary irrigation during establishment and for supplemental irrigation after establishment. Because of these initial irrigation needs, turf conversions are ideally implemented under non-drought conditions when irrigation is not restricted.

7. The details and quality of alternative landscape installations are critically important. For any of the various alternatives to irrigated turf identified in the white paper, there are aspects of design and installation that can significantly increase the runoff response including compaction of soils, types of plants used, density of plantings, and other factors. For any given type of turf conversion, there can be wide variability in rainfall-runoff performance depending on these factors. A poor installation of native vegetation could produce as much runoff as an approach with mostly mulch and little vegetation if soils are compacted and there is poor density of native vegetation.

8. For large-scale conversion efforts within a single drainage basin, the effects of the landscape conversion on runoff should be evaluated. For example, impacts to runoff vary depending on whether the irrigated turf is being replaced with less permeable cover (wood or gravel mulch with low density of plantings, installation with a shallow weed barrier, hardscape, etc.), or native grasses. In cases where the existing storm drainage system has been designed and constructed based on rainfall-runoff characteristics of irrigated turf, changes in peak runoff rates and volumes should be evaluated. In some cases, landscape-based detention for peak flow attenuation may be needed to mitigate

increase in peak rates and volumes of runoff. Any individual (single homeowner) turf conversion project may have minimal effects on the stormwater drainage system because of the typically small scale of such projects. However, the cumulative effects of multiple small-scale turf conversion projects or a few large-scale projects may be more substantial as small changes add up.

11.0 RESEARCH AND INFORMATION NEEDS

Based on the literature review completed for this white paper, WWE has identified several research and information needs to better evaluate the holistic environmental effects of turf conversion projects, including:

1. To further quantify the benefits of turf conversions, more refined quantification of the amount of irrigated turf and the portion of turf that is non-functional and the locations of these areas would be beneficial. For waterbodies identified as impaired for nutrients, there may be water quality co-benefits for converting irrigated and fertilized turfgrass to native grasses requiring lower nutrient inputs.

2. When turf conversion projects are planned and undertaken, accurate before-and-after water meter records can help to quantify actual water savings achieved following plant establishment for replacement landscapes.

3. To refine the understanding of water quality implications of turf conversions, field monitoring is needed for various types of land use conversions such as native grasses, mulched planted beds, and rock mulch. Water quality considerations include nutrients, sediment, herbicides/pesticides and thermal effects.[3]

4. Additional data are needed on rainfall-runoff characteristics for specific land cover types. As the literature review presented in Section 5.1 illustrates, there is a paucity of data on rainfall-runoff for alternative landscape types. Collecting regionally specific data from a variety of sites would contribute to a more empirically based quantitative understanding of how much runoff different types of land cover generate and how maintenance practices may affect performance over time.[6]

5. Given the challenges of weed control in turf conversion projects, further review and evaluation of weed barrier effects would be useful. A wide variety of weed barrier types are available with varying permeability and effectiveness at controlling weeds. More information is needed on types of weed barriers that are designed to allow for infiltration over time and best practices for installation (minimum cover, avoiding compacting subsoils during installation, etc.).

6. To meet turf removal goals, local governments that restrict herbicide use in their jurisdictions may need to consider exceptions for herbicide use on large-scale turf removal projects. Additional data sharing and continued review of EPA recommendations

[6] These recommendations are consistent with objectives included in the CWCB funded research project titled "Effects of Landscape Transformations on Urban Heat and Water Quality" led by Dr. Aditi Bhaskar, University of Colorado, beginning in 2024.

related to health and the environment should be considered to inform best practices for herbicide use.

7. With regard to urban heat considerations associated with turf conversions, additional field monitoring of the heat effects of various vegetation types, mulch types, artificial turf and hardscape would be useful to better quantifying urban heat island implications of turf conversions.

8. Given that non-functional turf removal in tree lawns may be targeted for removal to achieve water conservation goals, additional research and/or information related to the irrigation requirements of the trees is needed, given the multiple benefits of trees in Colorado communities and the desire to avoid unintended tree loss associated with turf conversions.

9. In many Colorado communities, receiving pervious areas (e.g., grass buffers and swales) and extended detention basins play an important role in managing stormwater quality and reducing runoff rates and volumes. Native grasses are currently encouraged in new vegetated stormwater facilities. Where turf conversion to native grasses is being considered for existing stormwater facilities, consultation with stormwater managers is necessary. Additionally, such retrofits may warrant additional collaborative research between water conservation and stormwater professionals to ensure that both water quality and water conservation objectives are achieved.

10. Continued refinement of best practices and guidance for landscape professionals who remove, install and maintain native landscapes is needed. Lessons learned from the Native Grass Working Group, CSU Extension, utilities and local governments involved with large-scale turf conversions and others should continue to be shared with landscape trade organizations (e.g., ALCC, CALCP, GreenCO) and associated Colorado-based conferences such as the Pro Green Expo. Similar efforts targeting landowners with smaller scale conversion projects are also beneficial.

12.0 REFERENCES

Acuña E., A.A., Pastenes V.C., Villalobos G.L. 2017. Carbon sequestration and photosynthesis in newly established turfgrass cover in central Chile. *Agron. J.* 2017, 109: 397–405.

Akbari, H., D. Kurn, S. Bretz, and J. Hanford. 1997. Peak power and cooling energy savings of shade trees. *Energy and Buildings*. 25:139-148.

Armstead, S., Carper, A., Davidson, D., Blanchard, M., Hopwood, J., Larcom, R., Black, S., Briles, C., Irwin, R., Jolma, G., Resasco, J., Davis, S., Mola, J., and Inouye, D. 2024. Colorado Native Pollinating Insects Health Study. Prepared for Colorado Department of Natural Resources. January. Native Pollinating Insects Health Study | Department of Natural Resources (DNR) (colorado.gov)

Bae, J., Ryu, Y. 2017. Spatial and temporal variations in soil respiration among different land cover types under wet and dry years in an urban park. *Landsc. Urban Plan.* 2017, 167: 378–385.

Bannerman, R.T., Owens D.W., Dodds, R.B., and Hornewer, N.J. 1993. Sources of pollutants in Wisconsin storm water: *Water Science Technology*, 28 (3-5): 241-259.

BBC Research & Consulting. 2024. Updated 2024 Exploratory Analysis of Potential Water Savings, Costs and Benefits of Turf Replacement in Colorado. CWCB: January 2024.

Benjamin, C. 2022. Is Artificial Turf a Beneficial Water Conservation Tool in the West? Western Resource Advocates, December 2022.

Bhaskar, A. 2024. Effects of Landscape Transformations on Urban Heat and Water Quality, Scope of Work for Grant Application to Colorado Water Conservation Board. Prepared by Aditi Bhaskar for the University of Colorado.

Booth, M. 2023. Colorado cities accelerate turf wars with new construction bans, public median rip-outs, Colorado Sun, October 10, 2023. https://coloradosun.com/2023/10/10/colorado-cities-turf-bans-grass-removal/

Boulder County. 2024. Boulder County Integrated Weed Management Plan. Version 3.0. Final Draft for BOCC. Accessible at: https://assets.bouldercounty.gov/wp-content/uploads/2024/04/Integrated-Weed-Management-Plan-V3.0.pdf

Bounds, A. 2024. Boulder County agrees to limit future herbicide use in weed plan, Boulder Daily Camera, May 2024. https://www.dailycamera.com/2024/05/23/boulder-county-agrees-to-limit-future-herbicide-use-in-weed-plan/

Carey, R.O., Hockmuth, G.J, Martinez, C. J., Boyer, T.H., Dukes, M.D., Toor, G.S., and Cisar, J.L. 2013. Evaluating nutrient impacts in urban watersheds: Challenges and research opportunities. *Environmental Pollution*, Volume 173, February 2013, Pages 138-149.

Carey, R.O., Hockmuth, G.J, Martinez, C. J., Boyer, T.H., Nair, V.D., Dukes, M.D., Toor, G.S., Shober, A.L., Cisar, J.L., Trenholm, L.E., and Sartain, J.B. 2012. A Review of Turfgrass Fertilizer

Management Practices: Implications for Urban Water Quality, *HortTechnology*, June 2012 22(3): 280-291.

Chang B, Wherley B, Aitkenhead-Peterson JA, McInnes K.J. 2021. Effects of urban residential landscape composition on surface runoff generation. Sci Total Environ. doi: 10.1016/j.scitotenv.2021.146977

Chiotti, D., L. Ritter, D. Schlenk, C. Wilen, K.C. Schiff. 2020. Alternatives to Glyphosate for Vegetation Management in Los Angeles County. Technical Report 1103. Southern California Coastal Water Research Project. Costa Mesa, CA.

City and County of Denver. 2024. Denver Turfgrass Study. Prepared with assistance of Biohabitats and Dig Studios. City and County of Denver: March 2024.

City of Boulder. 2024. Reducing Pesticides, Accessible on City of boulder website: https://bouldercolorado.gov/services/reducing-pesticides#:~:text=Pesticide%20use%20on%20city%20property,-Turf%20grass%20on&text=Almost%20all%20pesticides%20are%20banned,data%20and%20peer%2Dreviewed%20literature.

City of Fort Collins Utilities. Turf Removal.
https://www.fcgov.com/utilities/img/site_specific/uploads/turf-removal_saplus.pdf?1713281519

Colorado Department of Public Health and Environment (CDPHE) 2020. CDPS General Permit COR090000 Stormwater Discharges Associated with Stormwater Discharges Associate with Municipal Separate Storm Sewer Systems (MS4s) Authorization to Discharge under the Colorado Discharge Permit System. https://cdphe.colorado.gov/wq-municipal-ms4-permits

Colorado Springs Utilities. 2024. Summary of Risks Related to Using Glyphosate in Turf Conversion Projects.

Davis, J.G., Whiting, D., Loeszak, H., Hammond, E., and Murgel, J. 2024. Choosing a Soil Amendment – 7.235. https://extension.colostate.edu/topic-areas/yard-garden/choosing-a-soil-amendment/#

En-Plast Technology. 2021. “Drainage Capacity and Time to Drain Design Manual.”

European Food Safety Authority. 2015. Conclusion on the peer review of the pesticide risk assessment of the active substance glyphosate. EFSA J. 13 (11), 4302, https://doi.org/10.2903/j.efsa.2015.4302.

Fillo, N. K., Bhaskar, A. S., & Jefferson, A. J. 2021. Lawn irrigation contributions to semi-arid urban baseflow based on water-stable isotopes. Water Resources Research, 57, e2020WR028777. https://doi. org/10.1029/2020WR028777

Fontanelli, M., Pirchio, M., Frasconi, C., Martelloni, L., Raffaelli, M., Peruzzi, A., Grossi, N., Caturegli, L. Magni, S., Gaetani, M., and Volterrani, M. 2017. Steaming and Flaming for Converting Cool-season Turfgrasses to Hybrid Bermudagrass in Untilled Soil, *HortTechnology* 27(5). October 2017.

Golubiewski, N.E. 2006. Urbanization increases grassland carbon pools: Effects of landscaping in Colorado's Front Range. *Ecol. Appl*. 2006, 16: 555–571.
Gray, E. 2015. Vegetation Essential for Limiting City Warming Effects, on NASA Landsat Science Webpage: [Vegetation Essential for Limiting City Warming Effects | Landsat Science (nasa.gov)]

Gregory, J.H., Dukes, M.D., Jones, P.H., and G.L. Miller. 2006. Effect of Urban Soil Compaction on Infiltration Rate. *Journal of Soil and Water Conservation*, Vol. 61, No. 3., Soil and Water Conservation Society.

Hébert, M.P., Fugère, V., Gonzalez, A. 2018. The overlooked impact of rising glyphosate use on phosphorus loading in agricultural watersheds, *Frontiers in Ecology and the Environment*, 17:1 (48-56). https://doi.org/10.1002/fee.1985

Herb, W. R., Janke, B., Mohseni, O., and Stefan, H. G. 2007. Estimation of Runoff Temperatures and Heat Export from Different Land and Water Surfaces. Prepared for the Vermillion River Watershed Joint Powers Organization with support from Minnesota Pollution Control Agency.

International Agency for Research on Cancer. 2015. Evaluation of five organophosphate insecticides and herbicides. *IARC Monographs*. vol. 112, https://www.iarc.fr/wp-content/uploads/2018/07/MonographVolume 112-1.pdf.

Johnson, Z.S., Koski, A., and A. O'Connor. 2017. The Hidden Value of Landscapes: Implications for Drought Planning. Colorado State University: Fort Collins.

Kaye, J.P., McCulley, R.L., Burke, I.C. 2005. Carbon fluxes, nitrogen cycling, and soil microbial communities in adjacent urban, native and agricultural ecosystems. *Glob. Chang. Biol.* 2005, 11: 575–587.
Klett, J.E. 2020. Mulches for Home Grounds: Fact Sheet No. 7.214 Gardening Series. *Colorado State University Extension.*

Knight, T., S. Price, D. Bowler, et al. 2021. How effective is 'greening' of urban areas in reducing human exposure to ground-level ozone concentrations, UV exposure and the 'urban heat island effect'? An updated systematic review. *Environmental Evidence* 10, 12.

Koski, A. 2024. Some Thoughts and Observations on Conversions to "Native." Powerpoint presentation to the Native Grass Working Group.

Koski, A., and Skinner. 2012. Colorado Sate Extension Fact Sheet: Lawn Care – 7.202. https://extension.colostate.edu/topic-areas/yard-garden/lawn-care-7-202/

LeBleu, C., Dougherty, M., Rahn, K., Wright, A., Bowen, R., Wang, R., Orjuela, J. A., and Britton, K. 2019. Quantifying Thermal Characteristics of Stormwater through Low Impact Development Systems. *Hydrology* 6(1). DOI: 10.3390/hydrology6010016

Livesley, S.J., Dougherty, B.J., Smith, A.J., Navaud, D., Wylie, L.J., Arndt, S.K. 2010. Soil-atmosphere exchange of carbon dioxide, methane and nitrous oxide in urban garden systems: Impact of irrigation, fertiliser and mulch. *Urban Ecosyst*. 2010, 13: 273–293.

Mast, M.A., Campbell, D.H. Ingersoll, G.P. Foreman, W.T., Krabbehoft, D.P. 2003. Atmospheric Deposition of Nutrients, Pesticides, and Mercury in Rocky Mountain National Park Colorado, 2002. Water Resource Investigations Report 03-4241. U.S. Geological Survey.

McPherson, T. N., Burian, S. J., Stenstrom, M. K., Turin, H. J., Brown, M. J., & Suffet, I. H. 2005. Dry and wet weather flow nutrient loads from a Los Angeles Watershed. *Journal of the American Water Resources Association*, 41(4): 959–969. https://doi.org/10.1111/j.1752-1688.2005.tb03780.x

Medalie L., Baker N.T., Shoda M.E., Stone, W.W., Meyer M.T., Stets, E.G., and M. Wilson. 2020. Influence of land use and region on glyphosate and aminomethylphosphonic acid in streams in the USA. *Journal of Science of the Total Environment*, 7907 (2020) 136008.

Mile High Flood District. 2020. Topsoil Management Guidance. Accessible at: https://mhfd.org.

Mile High Flood District. 2024. Urban Storm Drainage Criteria Manual (with specific reference to Volume 1, Chapter 6: Runoff and Volume 3 Stormwater Best Management Practices). Mile High Flood District: Denver, CO. Accessible at: https://mhfd.org/resources/criteria-manual/.

Moravec C. 2024. Summary of Risks Related to Using Glyphosate for Turf Conversion Projects. Colorado Springs Utilities.

Multi-resolution Land Characteristics Consortium. 2024. National Land Cover Data Enhanced Visualization and Analysis Tool. Accessible at: EVA Tool (mrlc.gov).

Native Grass Working Group. 2024. Colorado Guide to Native and Water Wise Grass Installation and Maintenance. Accessible at: https://coloradonativegrass.org/.

Northern Water. 2024. Benefits of Warm Season Native Grasses. Accessible at: https://www.northernwater.org/what-we-do/protect-the-environment/efficient-water-use/landscape-resources/native-grasses#:~:text=Switching%20to%20a%20native%20grass,by%2019%20inches%20or%20more.

Pitt, R. E., Bannerman, R., Clark, S.E., and Williamson. 2004. Sources of pollutants in urban areas. In: Effective Modeling of Urban Water Systems, Monograph 13. James, Irvine, McBean & Pitt, Eds. ISBN 0-9736716-0-2 ©CHI2004 www.computationalhydraulics.com

Pitt, R.E. 2012. Compacted Urban Soils and their Remediation. Accessible at: https://winslamm.net/assets/files/presentations_and_publications/10%20Compacted%20Urban%20Soils/2012%20Pitt%20Compacted%20urban%20soil%20and%20remediation.pdf

Pitt, R.E., Maestre, A., Clary, J. 2018. The National Stormwater Quality Database (NSQD), Version 4.02. Accessible at: https://bmpdatabase.org/national-stormwater-quality-database

Pouyat, R.V., Yesilonis, I.D., Golubiewski, N.E. 2009. A comparison of soil organic carbon stocks between residential turf grass and native soil. *Urban Ecosyst.* 2009, 12: 45–62.

Qian, Y., Follett, R.F. 2002. Assessing soil carbon sequestration in turfgrass systems using long-term soil testing data. *Agron. J.* 2002, 94: 930–935.

Resource Central. 2024. Lawn Replacement Program. https://resourcecentral.org/lawn/

Salazar Center for North American Conservation at Colorado State University and Denver Parks and Recreation. 2024. Final Report for Optimizing Plant Choices to Maximize Pollinator Habitat, Climate Resilience, and Social Values across Denver Parks and Neighborhoods. June.

Schiavon, M., Barnes, B., Shaw, D., Henry, J., Baird, J. 2013. Strategies for Converting Tall Fescue to Warm-season Turf in a Mediterranean Climate, *HortTechnology*, 23(4) 442-448. August.

Schultz, R. 2023. Turf Ordinances and the Intersection of Water Conservation and Water Quality, Presented at Cherry Creek Annual Conference, August 2023.

Simpson, T. and Francis R. 2021. Artificial lawns exhibit increased runoff and decreased water retention compared to living lawns following controlled rainfall experiments. *Urban Forestry & Urban Greening*. doi: 10.1016/j.ufug.2021.127232

Stein, E. D., & Ackerman, D. 2007. Dry weather water quality loadings in arid, urban watersheds of the Los Angeles Basin, California, USA1. JAWRA Journal of the American Water Resources Association, 43(2), 398–413. https://doi.org/10.1111/j.1752-1688.2007.00031.x

Steuer, J., Selbig, W., Hornewer, N., Prey, J. 1997. Sources of Contamination in an Urban Basin in Marquette, Michigan and an Analysis of Concentrations, Loads, and Data Quality. U.S. Geological Survey Water-Resources Investigations Report 97-4242.

Taha, H., D. Sailor, and H. Akbari. 1992. High-albedo Materials for Reducing Building Cooling Energy Use. Lawrence Berkeley National Laboratory Report No. 31721 UC-350: 71.

Thompson, A. M., Kim, K., and Vandermuss, A. J. 2008. Thermal Characteristics of Stormwater Runoff from Asphalt and Sod Surfaces. *Journal of the American Water Resources Association, 44*(5), 1325-1336. DOI: 10.1111/j.1752-1688.2008.00226.x

Toor, G. S., Occhipinti, M. L., Yang, Y.-Y., Majcherek, T., Haver, D., & Oki, L. 2017. Managing urban runoff in residential neighborhoods: Nitrogen and phosphorus in lawn irrigation driven runoff. *Plos One*, 12(6), e0179151. https://doi.org/10.1371/journal.pone.0179151

Townsend-Small, A., Czimczik, C, I. 2010. Carbon sequestration and greenhouse gas emissions in urban turf. Geophysical Research Letters, 37(2). https://doi.org/10.1029/2009GL041675

Trammell, T.L.E., Pataki, D.E., Pouyat, R.V., Groffman, P.M., Rosier, C., Bettez, N., Cavender-Bares, J., Grove, M.J., Hall, S.J., Heffernan, J., et al. 2020. Urban soil carbon and nitrogen converge at a continental scale. *Ecol. Monogr.* 2020, 90, e01401.

U.S. Department of Agriculture. 2024. Pollinators Need Native Grasses Too! | Natural Resources Conservation Service (usda.gov)

U.S. Department of Energy. 2003. Energy Savers: Tips on saving money and energy at home. Energy Efficiency and Renewable Energy Clearinghouse.

U.S. Environmental Protection Agency. 2008. Urban Heat Island Basics - Draft. In *Reducing Urban Heat Islands: Compendium of Strategies*. https://www.epa.gov/sites/default/files/2017-05/documents/reducing_urban_heat_islands_ch_1.pdf

U.S. Environmental Protection Agency. 2016. Climate Change and Heat Islands. https://www.epa.gov/heatislands/climate-change-and-heat-islands. Accessed June 7, 2024.

United State Department of Agriculture, Natural Resources Conservation Service (USDA NRCS). 1986. Urban Hydrology for Small Watersheds, Technical Release 55 (TR-55). Accessible at: https://www.nrc.gov/docs/ML1421/ML14219A437.pdf

Upadhyay, S., Singh, R., Verma, P., Raghubanshi, A.S. 2021. Spatio-temporal variability in soil CO_2 efflux and regulatory physicochemical parameters from the tropical urban natural and anthropogenic land use classes. *J. Environ. Manag*. 2021, 295: 113141.

Velasco, E., Roth, M., Norford, L., Molina, L. T. 2016. Does urban vegetation enhance carbon sequestration? *Landscape and Urban Planning*, 148, 99-107. https://www.sciencedirect.com/science/article/abs/pii/S0169204615002455

Wang, J., Wang, X., Xu, Weitong, Xue, C., Li, H., Sun, Z., Zhang, C., and Li, J. 2023. Characteristics of Thermal Pollution from Stormwater Runoff from Impermeable/Permeable Pavement Surfaces via a Lab-scale Experiment. *Journal of Environmental Management, 325*. DOI: 10.1016/j.jenvman.2022.116484

Wang, R., Mattox, C.M., Phillips, C.L., Kowalewski, A.R. 2022. Carbon Sequestration in Turfgrass–Soil Systems. *Plants* 2022,11: 2478. https://doi.org/10.3390/plants11192478.

Waschbusch, R. 1995. Written Communication with USGA for Madison, WI, 1994-1995 street study, as cited by Steuer et al. 1997.

Weiss, K. and C. Moravec. 2023. USAFA Native Grass Trials Status Report. December 13, 2023. Project conducted by USAFA Energy and Utilities and Colorado Springs Utilities.

Whiting, D., Wilson, C., Moravec, C., and Reeder, J. 2023. CMG GardenNotes #245: Mulching. *Colorado State University Extension.*

Wright Water Engineers, Inc. 2008. Green Industry Best Management Practices (BMPs) for the Conservation and Protection of Water Resources in Colorado: Moving Toward Sustainability Prepared for The Green Industries of Colorado (GreenCO). Prepared with support from The Colorado Water Conservation Board Headwaters Consulting, LLC Colorado Department of Public Health and Environment Water Quality Control Division (under a grant from the U.S. Environmental Protection Agency).

Wright Water Engineers, Inc., Geosyntec Consultants, Pitt, R.E., Roesner, L. 2013. Colorado Regulation 85 Nutrient Data Gap Analysis Report. Prepared for the Mile High Flood District and Colorado Stormwater Council. Accessible at: https://mhfd.org.

Wright Water Engineers, Inc., Northern Water, and Aquacraft, Inc. 2015. Exploring the Role of Landscape Water Conservation and Efficiency in Meeting Colorado's Water Gap: Expected Benefits of Landscape Water Conservation Best Management Practices 2015 Update to GreenCO Literature Review. Prepared for GreenCO.

Appendix A

Colorado Spring Utilities Glyphosate Summary

Colorado Springs Utilities
It's how we're all connected

Summary of Risks Related to Using Glyphosate in Turf Conversion Projects

Catherine Moravec, Colorado Springs Utilities

Extensive scientific research and analysis show minimal risk from glyphosate from short-term use via terrestrial or water pathways if used in accordance with the label. As public opinions and perceptions influence policy and broader decision making, scientific research can provide valuable information from an empirical perspective.

Glyphosate and Turf Conversion Projects

- Glyphosate is the most common herbicide used to kill existing grass and weeds to prepare a site for a turf conversion project. Glyphosate is widely studied as it is the most commonly used herbicide in agriculture.
- During a turf conversion project, glyphosate is typically applied two to three times to kill existing vegetation and is generally not used again on the same site unless another landscape conversion project is undertaken.

Glyphosate and Water

- Glyphosate can legally be sprayed on land for terrestrial applications or directly on aquatic environments for water applications. Surfactants, such as POEA, are not allowed in formulations applied to water.
- Because glyphosate binds tightly to surface layer soil particles after it is applied, much of the glyphosate and AMPA in water are linked to direct applications to aquatic environments, spray drift from terrestrial applications, or transport of suspended soil particulates into water followed by desorption. AMPA is a byproduct of glyphosate degradation.
- AMPA is also a byproduct of the degradation of detergents. Therefore, not all the AMPA detected in water is linked to glyphosate degradation because some AMPA is from detergents.

Over the past decade, Environmental Protection Agency (EPA) scientists have performed an independent, rigorous evaluation of available data for glyphosate and found the following:

Human Health

- No risks of concern to human health from current uses of glyphosate.
- No indication that children are more sensitive to glyphosate.
- No evidence that glyphosate causes cancer in humans.
- No indication that glyphosate is an endocrine disruptor.

Environmental Risks

- Exposure to glyphosate residues from spray drift is not anticipated to impact the survival, growth, or reproduction of aquatic invertebrates or fish.
- Data suggest that toxicity to glyphosate exposure to honeybees is low, but more research is needed to determine the risks to honeybee larvae.

- Acute exposure toxicity to birds is likely to be low, but chronic exposure from repeated aerial applications may impact bird growth.
- Risks to mammals from both acute and chronic glyphosate exposure is likely to be low, but chronic exposure to formulations that contain the surfactant POEA may affect reproduction.
- Toxicity studies on predatory mites, earthworms, and parasitic wasps generally report no effects up to the highest dose tested.

For more information from the EPA about glyphosate, its uses, and risks, visit https://www.epa.gov/ingredients-used-pesticide-products/glyphosate

Comparison of Long-Term Landscape Chemical Applications

Landscape maintenance professionals usually use fewer chemical applications to maintain native grass areas than turfgrass areas as shown in Table 1. Converting turfgrass to native grass can reduce the frequency of landscape chemical applications over the long term. Chemical application reduction depends on the frequency of application prior to conversion.

Table 1: Typical Chemical Applications for Grass Maintenance in Colorado's Front Range

Chemical Type	Turfgrass Maintenance (applications per growing season)	Native Grass Maintenance (applications per growing season)
Fertilizer (synthetic or organic)	3 to 4	0 to 1
Pre-emergent weed control	0 to 2	0 to 2
Post-emergent weed control	0 to 4	0 to 2

Sources

Ingredients Used in Pesticide Products: Glyphosate. https://www.epa.gov/ingredients-used-pesticide-products/glyphosate#ecological, accessed March 12, 2024.

Lawn Care, Colorado State University Extension. https://extension.colostate.edu/topic-areas/yard-garden/lawn-care-7-202/, accessed March 13, 2024.

Preliminary Ecological Risk Assessment in Support of the Registration Review of Glyphosate and Its Salts. https://www.regulations.gov/document/EPA-HQ-OPP-2009-0361-0077, accessed March 12, 2024.