WWE
MEMORANDUM

To: Holly Piza, P.E., CFM, Brik Zivkovich, P.E, CFM
Mile High Flood District

Via email: hpiza@mhfd.org, bzivkovich@mhfd.org

From: Wright Water Engineers, Inc.
Andrew Earles, Ph.D., P.E., P.H., D.WRE and Victoria Hennon, E.I.T

Date: October 16, 2023

Re: Determination of Water-wise Landscape Imperviousness Criteria

This memorandum documents research into appropriate imperviousness values and runoff coefficients for different types of land cover including water-wise landscaping approaches. The objective of this work is to develop appropriate impervious values to represent effects of landscape practices on rainfall-runoff processes.

1.0 Approach

Runoff coefficients are dimensionless parameters that relate the peak runoff rate to the intensity of rainfall and can be derived from equations in the Mile High Flood District (MHFD) Runoff Chapter that relate runoff coefficients to imperviousness, HSG, and average storm recurrence interval. Because there is relatively little guidance on imperviousness and runoff coefficients for different types of water-wise landscaping, WWE's approach included review of literature, along with calculations based on local depression storage and infiltration assumptions, to estimate values of imperviousness to assign to water-wise land covers. This memorandum discusses literature and summarizes calculations related to imperviousness for western desert xeriscaping with gravel and wood mulch, native grass, and artificial turfs. Several approaches to translating the results of this research into criteria that can be applied for design are discussed.

Water-wise landscaping focuses on conserving water by using vegetation that requires less irrigation. Water-wise landscaping is made up of a spectrum of ground cover types, which can range from native turf grasses to gravel mulch with sparse native plants. According to City of Aurora's (CoA's) turf ordinance, the definition of water-wise landscaping encompasses shrubs, perennials, and warm-season grasses. In this work, WWE evaluated several points on the spectrum of water-wise landscaping including western desert landscaping with gravel mulch, xeriscaping with wood mulch, artificial turf, and warm-season grasses (also referred as native grasses).

To evaluate imperviousness of various types of water-wise landscapes, WWE started by reviewing available scientific and engineering literature on runoff from different types of low-water use surfaces. The runoff coefficient criteria within drainage criteria manuals in other semi-arid or arid regions were also reviewed. WWE performed calculations to estimate runoff coefficients and imperviousness based on curve numbers, as well as assessed the rainfall-runoff relationship using the initial and constant loss method for 2-year storm depths.

2.0 Methods and Results

2.1 Literature Review

There is a gap in the peer-reviewed literature regarding rainfall-runoff behavior for water-wise landscaping practices like xeriscape and artificial turf. The few papers that have reviewed the effects of xeriscape and artificial turf landscapes on surface runoff 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). Chang et al (2021) developed quadratic regressions equations for artificial turf, wood mulch xeriscape, gravel mulch xeriscape, and St. Augustine grass lawns with 2-years of continuous rainfall and runoff data. Data were collected for 24 individually irrigated plots that were sized by 4.1 meters by 8.2 meters.

The Natural Resource Conservation Service's (NRCS's) Technical Release 55 Urban Hydrology for Small Watersheds (NRCS, 1996, 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 (HSGs) and cover conditions are shown in Table 1. The curve numbers from TR-55 were incorporated in calculations to estimate a runoff coefficient and imperviousness of native grasses and desert landscaping.

Table 1. Curve Numbers from TR-55 for Pasture, Grassland, or Range and Western Desert Urban Areas

Cover Type and Hydrologic Condition	Hydrologic Soil Group			
	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, WWE conducted a review of various drainage criteria manuals in the southwest. The City of Albuquerque, New Mexico, for example, assigns CNs to different 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, slopes, and soil type. In instances of desert landscaping with gravel, a curve number 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 two types of desert landscaping: one with an impervious layer underneath (e.g., weed barrier), which has a runoff coefficient ranging from 0.55 to 0.95, and one without an impervious layer, which has a runoff coefficient 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, the 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 curve numbers or runoff coefficients for desert landscaping with a weed barrier, while lower values are specified for areas with native grasses and shrubs. There is not much research on runoff coefficients for artificial turf, and no known published runoff coefficients in other regional drainage criteria manuals.

2.2 Analysis

2.2.1 Western Desert Landscaping (Gravel Mulch)

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 and becomes less permeable over time. An example of western desert landscaping is shown in Photograph 1. Because runoff coefficients within 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 volume of runoff for 24-hour precipitation depth using NRCS curve numbers to compute losses and the volume of runoff for 2-, 5-, 10-, 25-, 50-, and 100-year events.

2. Calculate volumetric runoff coefficient by dividing the volume of runoff from the CN calculation by the total 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 Manual)

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

Because of the predominance of hydrologic soil group (HSG) C soils along the front range of Colorado, these calculations were performed for HSG C.

Photograph 1: Western Desert Landscaping (Gravel Mulch)

Based on this analysis, a CN of 85 (Natural desert landscaping, pervious areas only, HSG 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%. This is for the case without a weed barrier. As a point of reference, stormwater criteria for Maricopa County use runoff coefficients for desert landscaping without impervious under treatment ranging from 0.3 to 0.5, so the value calculated using this method falls within the published range in Maricopa County.

For the case with a weed barrier, the NRCS CN is 96 for all HSGs, reflecting the impermeable nature of the weed barrier. For HSG 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 could tend to lower CN values and runoff coefficients and may be more representative of landscaping practices in Aurora and along the Front Rance. In addition, native plants and shrubs on the 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, we believe that the estimates of imperviousness for western desert landscaping derived from TR-55 CNs tend to be on the high side.

2.2.2 Native Grasses

Installing native grasses is a practical solution for replacing nonfunctional grass. Photograph 2 illustrates native grass landscaping. The period to establish native grasses, like the blue grama or buffalo grass, 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 other species have more spreading growth and form denser strands. For native grasses, WWE evaluated several sources of information including current recommendations for imperviousness of lawns from the MHFD 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 of the fact that 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 weather turf grass, 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.

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.

Photograph 2: Native Grasses

2.2.3 Xeriscaping with Wood Mulch

There is very little data on runoff from areas with wood mulch landscaping. A typical example is shown in Photograph 3. 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 based on 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 hydraulic conductivity representative of HSG 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 Manual.

Results of those calculations indicate a 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 weed barrier for plantings, and effects of vegetation.

Photograph 3: Xeriscaping with Wood Mulch

2.2.4 Artificial Turf

An example of artificial turf is shown in Photograph 4. Artificial turf is made to be porous and let water through to the underlying soil. Compared to traditional grass 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 the values for xeriscaping practices.

Photograph 4: 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. 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 Manual.

According to the Synthetic Turf Council, the standard for water permeability is a minimum rate of ten 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. 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 would be adequate. 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.

3.0 Discussion

There are a wide variety of water-wise landscaping practices with varying imperviousness. The types of water-wise landscaping analyzed in this memorandum were desert landscaping with gravel mulch, xeriscaping with wood mulch, artificial turf, and native grasses. According to the analysis conducted in this work, imperviousness for these different landscaping practices ranges from 5% to 60%.

There are a few approaches that could be used to provide criteria for water-wise landscaping practices from a granular approach that breaks down specific land cover types to a broad approach that uses a single representative value. Potential approaches include:

- Granular Approach – One approach to presenting criteria would be to use a granular strategy, where there are distinct values assigned to each unique landscape type. The advantage to this strategy is that it allows the area weighted calculated imperviousness of a proposed development to be comprehensive because it can consider all different types of landscaping. The disadvantage of this approach is that specific landscaping types on lots may not be known in earlier stages of design. Therefore, engineers would need to make assumptions on the planned breakdown of different landscaping types at the preliminary and final drainage report stages of review. Another disadvantage is that property owners may change landscaping over time, so being overly precise may not necessarily improve accuracy in calculating runoff over the long run.

- Representative Value – A second option would use a single value to represent a range of landscaping. This approach provides simplicity for the engineer and developer during site design of a proposed development. An advantage to a single value approach is that it considers how landscaping could change from what it was designed originally, as in the case of a single-family home homeowner who wishes to change their desert landscaping with gravel mulch to a mixture of native grasses and xeriscape plantings with wood mulch. A single representative value could capture the variety of landscaping within a development and provide a reasonable basis for sizing drainage infrastructure, so long as it represents the potential variety of landscaping that could be implemented in the watershed and does not underestimate runoff. A disadvantage of this approach is that site-specific conditions could vary significantly from the "representative" value with some areas (i.e., native grass and cool weather turf areas) having less runoff potential and other areas (i.e., xeriscaping with a shallow weed barrier) having greater runoff potential. Because there is a wide range of variability in the actual rainfall-runoff response depending on the specific type of landscaping, using an average value has the potential to under or overestimate runoff. This point emphasizes the importance of setting a representative value for landscaping at a level that would be unlikely to underpredict runoff based on typical landscaping practices within local government.

- Hybrid Approach – A third option involves a mixture of the first and second option. For example, various types of vegetated landscaping could be lumped together with one impervious value, while distinguishing artificial turf and open spaces with native grasses as unique impervious values. An advantage of this approach is that it fits with the increasing level of information and detail available as a project progresses from master planning through final design. Using a representative value at the master planning stage would be appropriate given the level of detail, while using more granular values as drainage and landscaping plans are developed would result in appropriately sized infrastructure at the subdivision or lot scale.

4.0 Recommendation

Imperviousness for water-wise landscapes were estimated using the methods described above. With engineering and scientific judgement and input from the CoA and MHFD, recommended impervious values are presented in Table 2 below.

Table 2. Recommended Imperviousness for Surface Types

<table>
<tr><th colspan="2">Surface Type</th><th>Imperviousness</th></tr>
<tr><td colspan="2">Paved Streets</td><td>95%</td></tr>
<tr><td colspan="2">Concrete Drive and Walks</td><td>95%</td></tr>
<tr><td colspan="2">Roofs</td><td>95%</td></tr>
<tr><td rowspan="3">Gravel</td><td>No Traffic Areas (pedestrian use)</td><td>40%</td></tr>
<tr><td>Low Traffic Areas (maintenance paths and substations)</td><td>60%</td></tr>
<tr><td>High Traffic Areas (roadways and parking)</td><td>80%</td></tr>
<tr><td colspan="2">Landscaping (including managed turf/lawns [active turf], water-wise vegetation, uncompacted gravel, planting beds, etc.)</td><td>20%</td></tr>
<tr><td rowspan="2">Artificial Turf*</td><td>Landscape applications (with subgrade drainage layer)</td><td>25 - 45%</td></tr>
<tr><td>Sport fields withs underdrain pipe system</td><td>60 - 80%</td></tr>
<tr><td colspan="2">Native Grasses and Open Space Areas (undisturbed or decompacted soil)</td><td>5%</td></tr>
<tr><td colspan="2">Water Surfaces, including footprint of WQCV^</td><td>100%</td></tr>
<tr><td colspan="2">Historic Flow Analysis, Greenbelts, Agricultural</td><td>5%</td></tr>
<tr><td colspan="2">Newly Graded Areas</td><td>65%</td></tr>
</table>

*Consult with the manufacturer to get recommended value
^For the footprint of storage-based SCMs, assume no runoff during the Water Quality Event.

The following are notes on the recommendations in Table 2:

1. The imperviousness of 20% is recommended to represent a variety of landscaping, including water-wise landscapes (shrubs, perennials, and warm weather grasses), lawns, active turf, and uncompacted gravel for landscaping based on the analysis presented in this memorandum and discussions with the CoA and MHFD. While we conducted research to estimate imperviousness of various landscaping practices including types of xeriscaping, managed turf/lawns, re-established native grasses, and others, we found considerable variability in the results of research into runoff coefficients for different types of landscaping (especially xeriscaping) or no reliable local data on runoff from specific landscape/land cover types. As a result of this, and because landscaping may change over time due to homeowner preferences, we believe using a representative imperviousness of 20% for landscaping is reasonable and within the range of values we estimated from references in the literature. While

we have developed estimates that could be used for a more granular approach, the level of confidence in these values is low due to the limited amount of research we found on this topic. The 20% impervious value is considerably higher than current guidance for managed turf; however, when considering the effects of soil compaction and irrigation (which takes up some of the soil's water storage capacity), we believe these values are reasonable. This recommendation also helps to account for some landscaping practices such as gravel or mulch xeriscape landscaping that may have somewhat higher imperviousness than 20%, especially when a weed barrier is installed.

2. Values for streets, drives and walkways, and roofs were adjusted slightly from existing values ranging from 90 – 100% to a uniform value of 95% for all impervious surfaces including roads, roofs, sidewalks, and other hardscapes. This adjustment was made on the basis that all of these types of fully impervious surfaces behave the same from a hydrologic standpoint and there is no strong technical basis for varying values for these types of surfaces from 90 – 100%. These values are included for the sake of presenting a comprehensive set of imperviousness values, even though the focus of this memorandum is on landscaping practices.

3. Values for gravel are based on research conducted by MHFD and WWE, as well as comments from a number of practitioners. The 40% value for no traffic areas is consistent with current MHFD criteria, and the higher values recommended for traffic areas are based on compaction of these surfaces to support vehicles and further compaction by vehicles using the areas.

4. Artificial turf imperviousness is distinguished between landscaping applications as well as sport fields that have underdrain systems that may convey more runoff to the storm drain system.

5. An updated value of 20% is provided for managed turf/lawns that are constructed on soils that are disturbed during development and compacted (typical practice). These types of turf areas are also irrigated, which reduces the available soil moisture storage capacity. We have included managed turf/lawns in the landscaping impervious value of 20% in Table 2.

6. We have not varied imperviousness values by HSG because Table 6-5 of the MHFD Manual makes an adjustment for HSG when calculating runoff coefficients.

5.0 References

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

En-Plast Technology. (2021). "Drainage Capacity and Time to Drain Design Manual." <https://enplast.us/wp-content/uploads/2021/12/ShockDrainDesignManual-12-6.pdf>

Mile High Flood District (MHFD), (2018, Revised). Urban Storm Drainage Criteria Manual Volume 1, Chapter 6: Runoff. <mhfd.org/wp-content/uploads/2019/12/06_Runoff-August-2018.pdf>

Simpson TJ and Francis RA. (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

United State Department of Agriculture, Natural Resources Conservation Service (USDA NRCS, 1986). Urban Hydrology for Small Watersheds, Technical Release 55 (TR-55).