Urban Trees and Water Conservation: A Comparison of Soil Moisture at Sites with Rain Gardens versus Drip Irrigation

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Santa Fe WATERSHED ASSOCIATION

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INTRODUCTION

As communities across the Southwest grapple with the impacts of climate change, many organizations, planners, and individuals might be less familiar with the impacts of the urban heat island (UHI) effect. Densely populated areas with large expanses of impervious or bare soil surfaces, such as parking lots, often reach warmer temperatures than surrounding rural or undeveloped areas (Figure 1). The effects of UHI can be particularly pronounced during the night as heat radiates off warm surfaces during times that should be cooler. Impervious surfaces also lack plant cover and moisture in the upper soil profile, which can help cool areas down through evapotranspiration. Ultimately, warmer temperatures can lead to greater energy consumption for cooling (e.g., air conditioning), resulting in more greenhouse gas emissions that contribute to climate change.

Figure 1. Urban heat island map (yellow, orange, red indicate increasingly hot temperatures) showing above-average surface temperatures resulting from impervious parking lots and dark rooftops compared to the shade canopy along an arroyo corridor in Santa Fe, NM (left). It is not uncommon for unshaded impervious surfaces (top right) to have temperatures substantially warmer than adjacent tree shaded surfaces (bottom right) by midday (117.6ºF vs 93.5ºF appx. 15ft apart). UHI map from ArcGIS and the Trust for Public Land.

Whereas massive resources, government commitment, widespread industrial transition, and long periods of time are needed to meaningfully address climate change, the methods to mitigate UHI could be achieved through a network of smaller groups and local organizations in a shorter amount of time. One of the simplest methods to reduce UHI could be through increased vegetation cover, including tree canopy, above parking lots. In communities around the semiarid Southwest, however, establishing and maintaining trees requires careful consideration around scarce water resources (Schuch 2018).

Drip irrigation is commonly used to reduce water consumption in semiarid regions by directly applying water near the base of a tree. While this irrigation method can conserve water better than flood irrigation or sprinkler systems, the practice is dependent on highly filtered water resources. Most drip systems use potable water, which is higher quality than is necessary for trees and costs $0.02/gallon after initial delivery fees in Santa Fe (City of Santa Fe). Additional costs for drip systems include pipes, seasonal maintenance and repairs, as well as energy for pumping/conveyance. Finally, there is the dilemma that as a tree matures, its roots will presumably outgrow the isolated location of irrigation emitters near the root collar. The New Mexico Office of the State Engineer (2017) recommends that established trees should be irrigated once every couple of weeks, 2-3 feet deep in the soil profile, and beyond at least half the distance from the trunk to the branch drip line. Failure to expand the radius of the drip emitters beyond the base could result in unhealthy or short-lived urban trees. Alternatively, stormwater runoff from impervious surfaces that is passively harvested in Green Stormwater Infrastructure (GSI), such as rain gardens, could offer a means to more broadly irrigate the soil volume below shade producing plants without pumps, filtration, and other requirements for drip. The challenge, however, is determining whether vegetation can survive with the variable timing and volumes of stormwater runoff.

STUDY BACKGROUND

In the fall of 2021, Santa Fe Public Schools set out to examine soil moisture at school parking lots with rain gardens compared to conventional raised medians with drip irrigation. The schools, Milagro Middle School and Santa Fe High School (SFHS), are located less than 0.5-miles apart (Figure 2). Soil moisture probes were installed at 6, 12, 18, and 24 inches below the soil surface approximately 5 feet south of 2-inch caliper trees planted in the fall of 2019 and spring of 2020. The two medians (350 ft^2) at Milagro each received a bur oak (*Quercus macrocarpa*) tree with drip emitters capable of applying roughly 12 gallons/hour of water approximately 1ft from the root collar. The probes at SFHS were installed in two (out of 24) parking spaces retrofitted as rain gardens (150 ft^2). The two monitored rain gardens were planted with an imperial honeylocust (*Gleditsia triacanthos* var. *inermis* 'Impcole') and Frontier elm (*Ulmus minor X Ulmus parvifolia* 'Frontier') tree. Stormwater from about 3,500 ft^2 of asphalt parking areas was directed to each rain garden with a pooling volume of about 600 gallons. Assuming a 0.8 runoff coefficient (i.e., 80% of precipitation will flow off a surface), then a 1/3-inch storm event is needed to fill each basin (i.e., 600-gallon volume/1,744 gallons in a 1-inch storm from 3,500 ft^2 = 0.34-inches).

Whereas trees in the medians at Milagro typically receive 45 minutes of drip irrigation (i.e., 9 gallons) every other day during the growing season (April-October), the trees in the rain gardens monitored at SFHS only receive irrigation from runoff during storm events. Precipitation measurements were taken using a tipping bucket rain gauge located between the two sites and were compiled into daily totals. The soil moisture probes monitored volumetric water content (VWC) every hour during the study period before measurements were averaged to daily values.

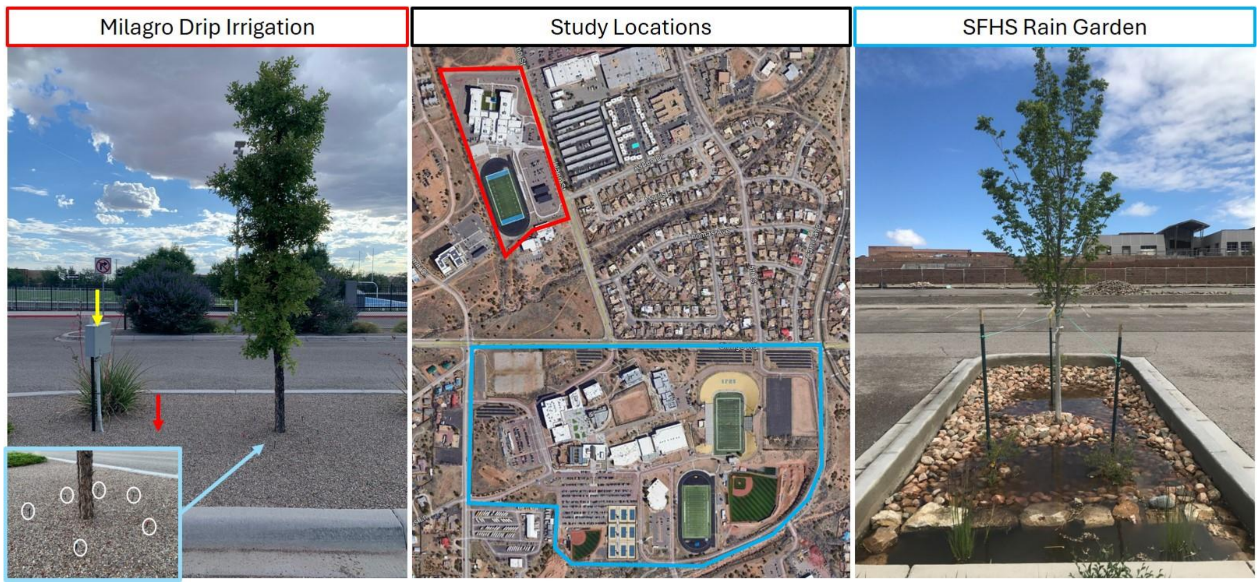
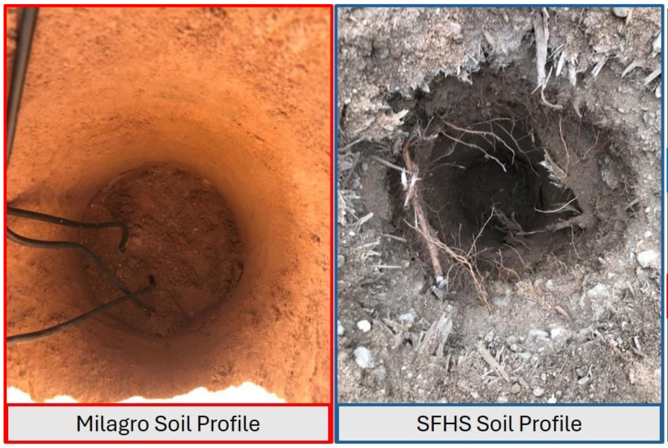


Figure 2. The campuses (center photo) of Milagro (red) and SFHS (blue) are located less than 0.5-miles apart. Example of a raised median (photo to left) with drip irrigation emitters (white circles) approximately 1ft from the root collar compared to a parking space retrofitted as a rain garden (photo to right) that is only irrigated during stormwater runoff from precipitation events. A soil moisture data logger (yellow arrow) and approximate location of subsurface VWC probes (red arrow) can be seen in the photo to the left.

Volumetric water content refers to the percentage of the soil volume that contains water. The value depends on soil texture, which is a measure of the proportion of fine, moderate, and coarse material (e.g., clay, silt, sand) in a sample. Both study sites probably lack well-developed soil horizons due to grading by heavy machinery to establish the parking lots. However, during the installation of monitoring equipment, an analysis of soil textures at both study sites revealed similar gravelly sandy loams at 18 inches in depth (Logan Peterson, Natural Resources Conservation Service) (Figure 3). Sandy loam textures tend to drain faster than soil with a greater proportion of fine material (e.g., clay loam). The maximum and minimum values for plant available water content (i.e., field capacity and permanent wilting point) in a sandy loam soil are 21.4% and 9.9% respectively (Ratliff et al. 1983). Studies have shown, however, that amending soil with organic matter can positively influence field capacity (Hudson 1994). In the case of the rain gardens at SFHS, approximately 2 cubic yards (i.e., 4-5 inches depth over 150 ft^2) of compost with woodchip fragments were integrated into the top 2-3 feet of the soil during installation.



Soil name	Horizon	Depth (cm)	Texture	% Sand	% Silt	% Clay	Soil OM (estimated)*
SFHS Rain garden	A1	0-4	extremely gravelly sandy loam	75	11	14	3
SFHS Rain garden	A2	4-32	very gravelly sandy loam	75	10	15	3
SFHS Rain garden	A3	32-60	very gravelly sandy loam	75	11	14	0.8
SFHS Rain garden	C	60-75	gravelly sandy loam	90	4	6	0.1
Milagro Median	C1	0-39	loam	45	32	23	0.2
Milagro Median	C2	39-47	very gravelly sandy loam	65	18	17	0.2
Milagro Median	C3	47-58	gravelly sandy loam	85	5	10	0.1
Milagro Median	2Btb	58-63	sandy clay loam	50	20	30	0.2
Milagro Median	2Ckb	63-100	loam	50	32	18	0.1

Figure 3. Images of soil profiles during soil moisture probe installation at Milagro and SFHS. While the rain garden soils have a higher proportion of organic matter integrated into the profile compared to the Milagro site, soil textures were similar at both sites at 18 inches (~45cm) in depth, which makes comparison of VWC easier.

Soil moisture volumes greater than field capacity (FC) indicate saturated soil conditions in which excess water can move into (i.e., recharge) adjacent pore spaces (e.g., laterally or downward). Moisture levels below permanent wilting point (PWP) are indicative of conditions when common agricultural crops (e.g., soybeans, corn) become incapable of extracting water from a soil texture. Drought-tolerant trees, however, might withstand values below PWP for a period of time. Theoretically, maintaining soil moisture between FC and PWP should sustain urban trees without supplemental irrigation once plants are established. For example, in a study of rain gardens with predominantly clay loam soil textures (i.e., finer texture than at Milagro and SFHS) and a composted woodchip mulch, VWC averaged across a 30-inch soil profile never fell below PWP over seven years; even during ten periods of time without measurable precipitation for 28 or more consecutive days (Kauffman and Stropki 2022).

The presence of sandy loam soil textures at SFHS and Milagro at 18 inches in depth allows for easier comparisons of VWC between school sites. The depth of 18 inches is also less likely to be influenced by evaporation compared to shallower depths (e.g., 6 and 12 inches) meaning that the soil moisture values should be indicative of water almost exclusively available to plants for transpiration. Based on these variables, the following results comparing irrigation from drip and passive stormwater irrigation could help with future planning around water conservation for trees intended to address UHI.

RESULTS AND DISCUSSION (2022-25)

General Differences

During measurements of VWC from January 1, 2022-December 31, 2025, there were occurrences where individual probes or data loggers failed to record measurements (e.g., lost battery power). Average measurements of VWC at 18 inches were omitted from these periods; however, general differences in soil moisture are apparent in Figure 4. Whereas VWC in the drip irrigated medians at Milagro generally hovered just below FC, there was much greater variation in the rain gardens at SFHS, particularly during the warmer months. The spikes in rain garden VWC are clearly in response to pulses of runoff during precipitation events while the more extreme dips toward PWP are during warm and dry periods that probably had higher evapotranspiration rates.

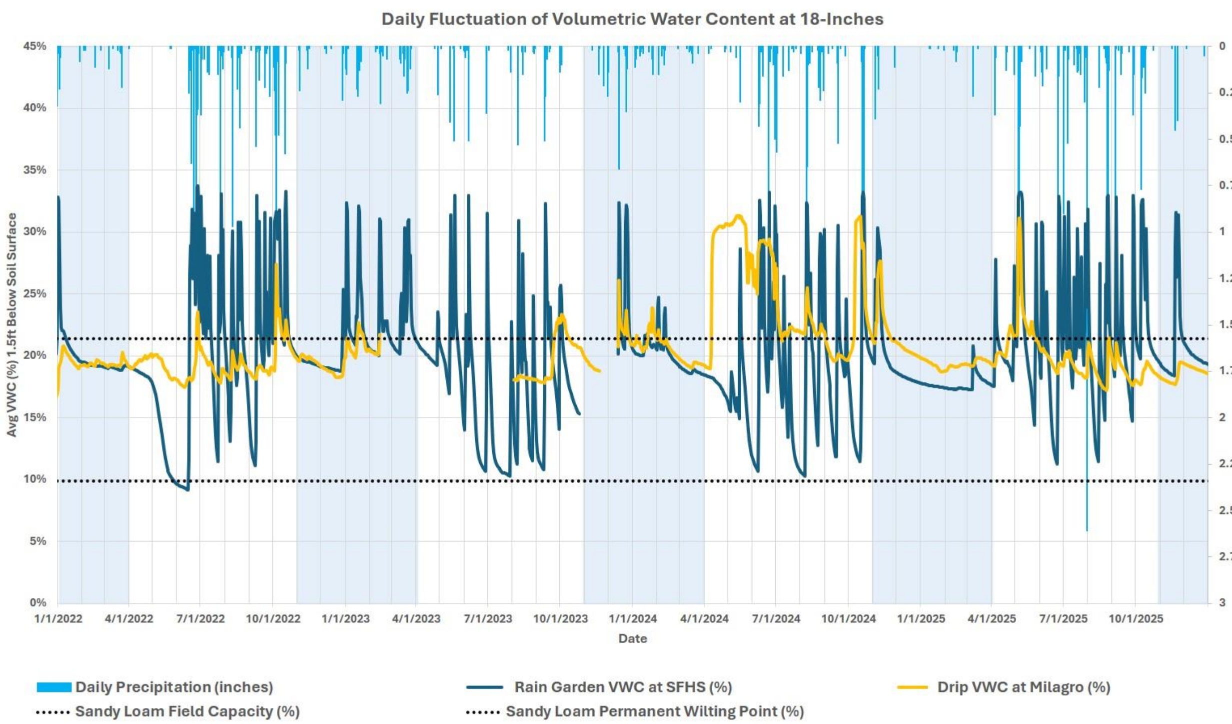


Figure 4. Fluctuations in VWC over four years at raised medians with drip irrigation at Milagro (yellow line) compared to SFHS rain gardens (dark blue line) with precipitation events (turquoise bars). Cool/dormant seasons are shaded in light blue while field capacity (FC) and permanent wilting point (PWP) are noted as the top and bottom dotted lines respectively. Missing sections of VWC lines could be the consequence of expired batteries in the data loggers.

Over the four years of study, average VWC at 18 inches deep in the rain gardens was 19.8% versus 20.7% in the medians with drip irrigation. Average VWC values in the rain gardens were lower (19.4%) in the warm/growing seasons (April-October) and higher (20.3%) during the cool/dormant seasons (November-March). These values likely indicate that evapotranspiration processes were extracting more water during the warm season (i.e., higher ET). Still, the rain gardens efficiently captured and stored soil moisture when plants were dormant. Conversely, average VWC at Milagro was higher in warmer seasons (21.2%) compared to cool seasons (19.9%), possibly indicating a high application of water for trees during the growing period and/or low replenishment of soil moisture during the winter.

Periods of Drought and the Cost of Irrigating Urban Trees

During the four years of monitoring, average VWC at 18 inches in depth fell below PWP in the rain gardens from May 29-June 15, 2022 (i.e., 18 out of 1,461 days or 1% of time) (Figures 4 and 5). While the length of time below PWP was brief in the context of the four years of study, the dry conditions could be problematic if trying to maintain healthy urban trees in the absence of other forms of supplemental irrigation. The more extreme lows in VWC occurred during the exceptionally dry spring of 2022, but conditions might have been compounded by the coarse textured soil (i.e., sandy loam) in the rain gardens. Sandy loams can be well drained and might have a narrower band of plant available water content (i.e., VWC range between FC and PWP) compared to other finer textured soils (e.g., clay loam). While the rain garden soils were amended with organic matter, it is possible that a greater application of material (e.g., compost or a thick layer of woodchips beneath the cobble mulch) might have further increased soil moisture retention and/or reduced ET loss.

Figure 5. Images of the frontier elm (left) and honeylocust (right) trees in rain gardens at SFHS during the initial stages of PWP at 18 inches in soil depth. The photos were taken on June 2, 2022 after having received only 1.07-inches of precipitation in the first five months of the year. Average VWC at 18 inches in the rain gardens on the photo date was 9.6%. Average water potential (another method to assess soil moisture by measuring negative pressure) measurements taken at the same depth was -2,174 kPa with -1,500 kPa indicative of PWP.

Total precipitation from January 1-March 31, 2022 amounted to 1.04 inches which is approximately half of the long-term average (2.07 inches at "Santa Fe 2" Weather Station, US Climate Data). The following 2.5 months only had 0.03-inches of precipitation. The regionally dry conditions resulted in the containment losses on the Hermit's Peak and Calf Canyon fires near Santa Fe, which ultimately burned over 300,000 acres.

Drip irrigation was turned on at Milagro on April 6th. Whereas most landscapes irrigated with drip likely use water treated to potable levels, SFPS made exceptional efforts to conserve water by installing a 40,000-gallon cistern at the school in 2018 (Figure 6). Despite those efforts, the dry conditions of 2022 resulted in the cistern being depleted (assuming it was full on April 6th) before May 15th (Figure 7). This meant that the drip irrigation at the site utilized potable water from the City of Santa Fe until precipitation needed to replenish the tank resumed in mid-June.

Figure 6. Installation of a 40,000-gallon cistern in 2018 at Milagro for irrigation purposes. Photo courtesy of Reese Baker.

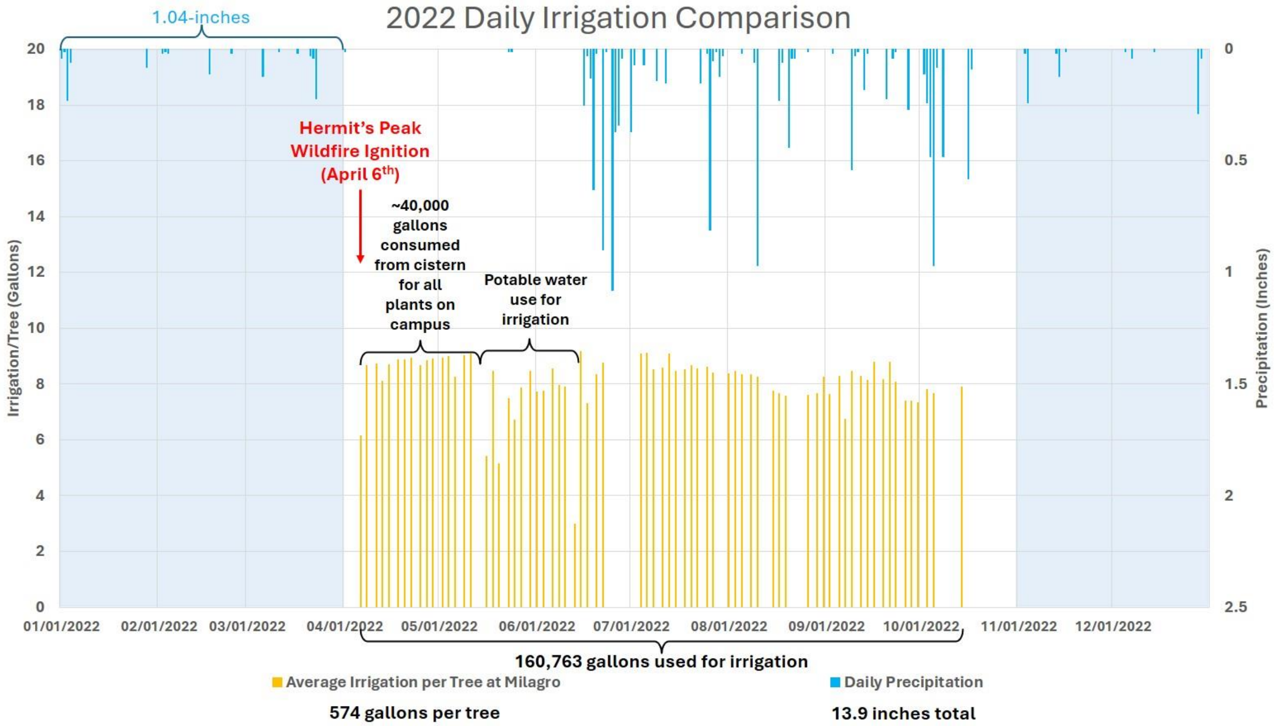


Figure 7. Estimated irrigation per tree at Milagro during 2022 along with precipitation during the cool (light blue area) and warm (white area) seasons. Irrigation is turned off during the dormant season.

The application of drip at Milagro maintained VWC near field capacity during the extreme drought conditions (Figure 8). The elevated soil moisture conditions raise the question of whether cutting back on irrigation (e.g., frequency and/or amount of water) to prolong the cistern's volume could have been achieved without a negative effect on vegetation. For example, in a study of several tree species in an arid climate that received different levels of irrigation, including simulated periods of drought, trees across treatments showed similar levels of growth and health for three growing seasons before some demonstrated ill effects at lower water applications (Schuch and Martin 2017).

As noted above, most sites that use drip are unlikely to have cisterns and thus would be drawing on potable water sources for irrigation needs. At a rate of $0.02/gallon, the cost of water for irrigation at Milagro during 2022 would have been approximately $11.50/tree or $3,215 for all plants at the site. This might seem inconsequential if not for the City's monthly utility connection/conveyance fees and threshold surcharges, initial costs for irrigation materials (e.g., pipe, emitters, valves, pumps, etc.), long-term maintenance of the system (e.g., leaks, seasonal turn on/off), and potential component/system replacement over time.

While rain gardens have their own set of unique costs (e.g., sediment trap maintenance), if a primary objective in semiarid communities is to conserve water, then the water catchment volumes and financial savings of basins are compelling. For example, if the same \$0.02/gallon value was applied to the stormwater (note that trees do not need water quality that meets drinking standards) harvested in the rain gardens (i.e., storms ≤0.35-inch), then each basin tree would have received an equivalent of 15,396 gallons or \$308 in water during 2022 (Table 1). The total runoff harvested at the site's 24 rain gardens for 2022 would have been 369,500 gallons or \$7,390 gallons of free water. The values continue to resonate financially when considering that each rain garden captured over 71,000 gallons (>\$1,400 at \$0.02/gallon) of runoff from 2020-25 without any pipes, pumps, etc.

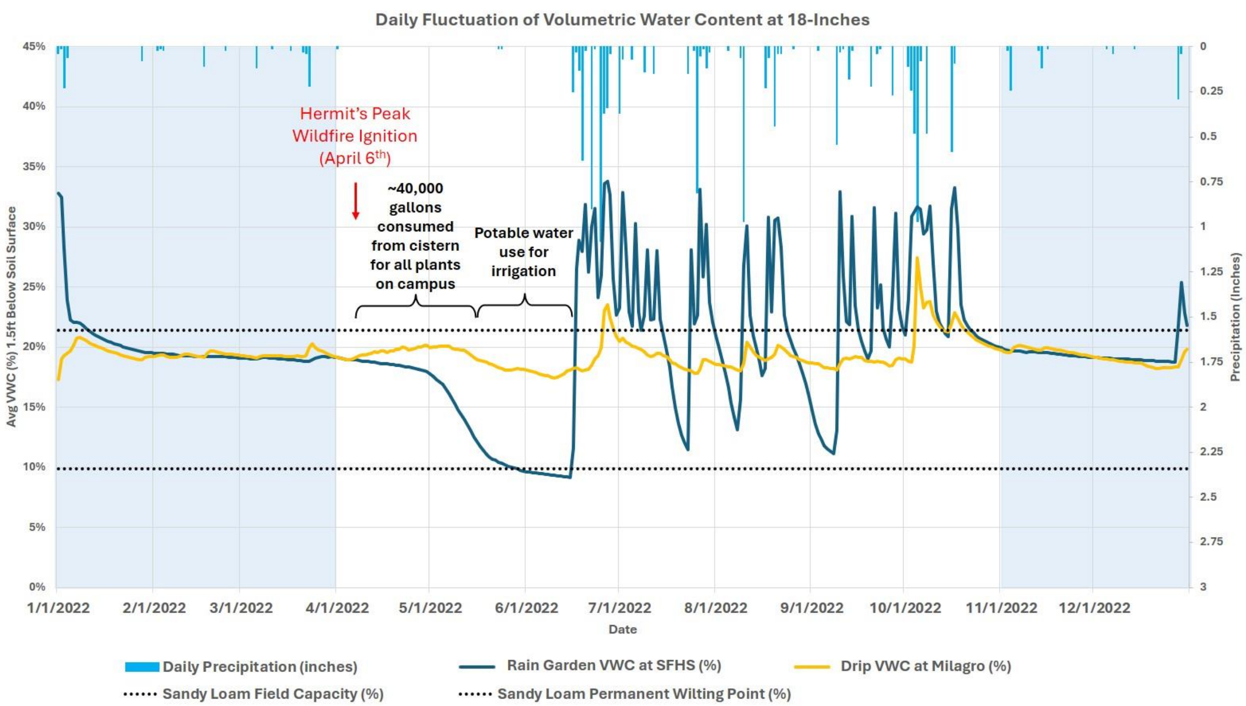


Figure 8. VWC at Milagro and SFHS during 2022. Cool/dormant seasons when irrigation is turned off are shaded in light blue. Aside from 18 days from late May to mid-June, average VWC in the rain gardens remained above PWP.

Table 1. Annual volumes of stormwater runoff and catchment at SFHS rain gardens. Storms less than 0.10-inch are omitted because they are unlikely to generate meaningful runoff.

SFHS Student Parking Lot Rain Garden Water Harvesting by Year						
Year	**Total Precipitation from Storms ≥ 0.10-inch**	**Total Stormwater Runoff per 3,500 ft^2 of Impervious Area (gallons)**	**Stormwater Harvested Per Rain Garden by Year (gallons)* Max. 0.35-inch Storm**	**Total Stormwater Runoff from Impervious Area with RG Catchment (gallons)**	**Total runoff harvested by 24 basins in student parking (gallons)**	**Percentage of Annual Runoff Captured**
2020	5.22	9,111	6,773	218,655	162,541	74%
2021	6.30	10,996	9,827	263,894	235,845	89%
2022	13.46	23,492	15,396	563,812	369,500	66%
2023	8.55	14,923	11,921	358,142	286,114	80%
2024	11.46	20,002	12,271	480,036	294,508	61%
2025	17.36	30,299	15,326	727,176	367,825	51%
Total	**62.35**	**108,822**	**71,514**	**2,611,717**	**1,716,334**	**66%**

Soil Moisture, Trees, and Urban Heat Islands

While the rain gardens did slip below PWP, the substantially larger volumes of water entering the basins around trees compared to medians with drip could have long-term benefits. By exceeding the needs of vegetation during moderate/large storms or while plants are dormant, runoff entering rain gardens might serve to recharge soil moisture beneath/beyond root lengths. Increased rain garden soil moisture in adjacent soil profiles could help sustain trees as they mature and root into areas that unexpanded drip irrigation might never reach. If the broader soil moisture in rain gardens supports a larger canopy over time, then the increased interception of sunlight and shade production above heat-retaining surfaces will be enhanced (Figure 9). Beyond tree cover, higher VWC levels in shallower parts of the rain garden soil profile could also cool surrounding temperatures through evaporation processes (Bowler et al. 2010).

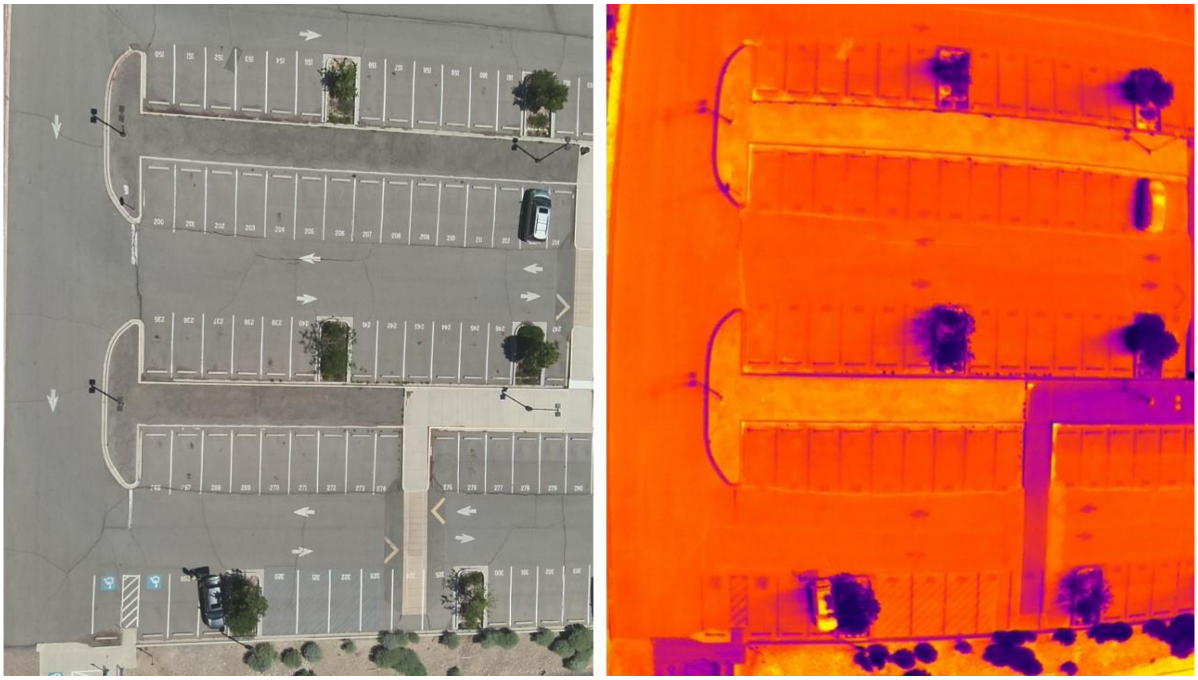


Figure 9. Conventional (left) and thermal (right) images of six rain gardens at SFHS taken at 11am in late July 2026 show the potential cooling value of trees and moist soils through evapotranspiration processes. The orange areas of asphalt were approximately 120℉ while the shade under the trees (dark purple areas) was 89℉. Images courtesy of Tammy Huynh and Eva Schwendimann (Southwest Environmental Finance Center).

CONCLUSION

Mitigating the impacts of the UHI effect might be achieved through increasing soil moisture levels that improve tree canopy and evapotranspiration processes. In semiarid communities, however, irrigating trees with scarce water resources can be a difficult decision for water planners and managers. Drip can be an effective method to conserve water for urban trees compared to other irrigation methods, but it still relies on filtered, and often potable water resources. Installing additional infrastructure such as pipes, pumps, filters, etc., can also be a financial burden. Even if the drip is more efficient than other irrigation types, it can still be overapplied (e.g., frequency and/or volume), leading to undesired consumption of water resources.

Soil moisture monitored at a school with drip irrigation demonstrated the efficacy of irrigation around young trees in a parking lot median. VWC at 18 inches in depth never approached PWP, which allowed trees to easily access water in the root zone. The value of drip at the site was enhanced by the fact that water used for irrigation generally originated from roofwater captured in a large cistern. Despite water conservation efforts at the site, however, the overapplication of drip irrigation during an intense period of drought drained the cistern, drawing on potable water resources. Considering most sites that use drip irrigation are likely to utilize potable water, the potential financial costs and burden on water resources could be higher than expenses incurred at Milagro. It is also worth considering that as trees in the medians mature, larger and/or broader applications of water might be needed to sustain growth.

Soil moisture levels monitored in rain gardens that capture stormwater runoff indicate that VWC can generally be maintained above PWP. Times when VWC dipped below PWP occurred during an exceptionally dry spring in 2022, but the dry conditions might have been compounded by well-drained, coarse textured soil at SFHS. Selecting drought-tolerant urban trees (i.e., species capable of surviving periods of soil moisture below PWP) and amending soil with higher amounts of organic matter, including organic mulches on the surface, might help buffer trees from drought in other similarly coarse textures such as sandy loams. Over time, urban trees in rain gardens might become more resilient to drought as they mature and roots can tap into the larger volumes of runoff from impervious areas that saturate broader areas within the basin soils compared to raised medians with drip irrigation.

AFTERWORD

Given the success of rain gardens at SFHS, SFPS has adopted the practice of installing GSI at other school sites. As of the summer of 2026, over 40 parking spaces retrofitted as rain gardens have been installed at numerous parking lots across four schools (SFHS, Nye Early Childhood Development, Early College Opportunities, and Kearny) to help improve tree cover. Soil moisture monitoring at Milagro and SFHS is ongoing and despite occasional dry conditions and having not received supplemental irrigation since June 2021, the trees in the two rain gardens monitored for soil moisture at SFHS continue to thrive.

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ADDITIONAL RESOURCES

Parking Space Retrofit Rain Garden Design (pp. 24-27)→ Green stormwater infrastructure: Low impact design strategies for desert communities. 2026. Santa Fe County Sustainability Division. https://www.santafecountynm.gov/uploads/documents/260513_SFC_GSI_Guidebook_Spreads.pdf

Video Highlighting the Rain Gardens at SFHS courtesy of Brad Lancaster, HarvestingRainwater.com→ https://www.youtube.com/watch?v=P1BuR4wRKtU

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Aaron Kauffman has over twenty years of experience analyzing and implementing simple, pragmatic solutions to watershed degradation including reforestation projects as a Peace Corps volunteer in the Dominican Republic, monitoring and evaluation of pre- and post-fire erosion rates in oak savanna and ponderosa pine environments, and stream restoration around the Southwest. Aaron founded Southwest Urban Hydrology LLC in 2012 and currently focuses on designing and implementing GSI in public and private spaces around New Mexico.