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Supplied by the Sky: The First Rainwater-Sourced Public Water System in Texas, USA

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Abstract: Central Texas is expected to face water availability challenges as climate change intensifies drought and the population continues to increase dramatically. To mitigate these impacts, the Campsite at Shield Ranch implemented (1) the first public water system in Texas approved by the Texas Commission on Environmental Quality to be fully supported by rainwater harvesting and (2) evaporative waterless toilets—also a first for Texas. Their methods exemplify integrated water management, or One Water strategies, which offer alternatives to help meet water demands while minimizing the withdrawal of groundwater and surface water. This paper explores the Campsite's rainwater-harvested public water system, water reduction and conservation strategies, energy generation and permitting processes. Supplied by the sky, the off-grid Campsite models how to effectively meet potable water demands in Central Texas with rainwater and water conservation while navigating a permitting system not (yet) designed to implement such novel, decentralized approaches.

Key words: Texas, water scarcity, water supply, rainwater harvesting, public water system

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Terms used in paper

Acronym/Initialism	Descriptive Name
ADA	Americans with Disabilities Act
BESS	battery energy storage system
H.B.	House bill
LCRA	Lower Colorado River Authority
mg/L	milligrams per liter
NTU	nephelometric turbidity units
psi	pounds per square inch
PWS	public water supply
RWH	rainwater harvesting
SCADA	Supervisory Control and Data Acquisition
TAC	Texas Administrative Code
TCEQ	Texas Commission on Environmental Quality
TWDB	Texas Water Development Board

INTRODUCTION

Unprecedented drought, accelerating population growth, and decreasing water supplies pose significant challenges to resilient water supplies in Texas (Cook et al., 2015; Cardone & Howe, 2018). In Central Texas—one of the fastest-growing regions of the state and nation (Texas Water Development Board [TWDB], 2022)—the Campsite at Shield Ranch is working at the nexus of land and water conservation, environmental stewardship, and nature connectedness and created Texas' first permitted rainwater harvesting (RWH) system for a public water system. Strategies, innovations, and trials were necessary for the successful development and implementation of this pioneering RWH system for potable water. The adoption of this system serves as a model for statewide applications of potable water supply strategies and can transform how society perceives, values, and manages water resources. We assess these strategies using the example of the Campsite at Shield Ranch, delving into the status of water resources in Texas with a focus on RWH, considering One Water approaches, and offering insights into the state's first permitted RWH potable public water system with conveyance.

Water in Texas

With over 30 million residents, Texas is a "diverse society straddling an aridity gradient" (Nielsen-Gammon et al., 2020, p. 1) that experiences variations in water stress, transitioning from dry to wet conditions moving west to east (Banner et al., 2010). In Texas, water is essential to supporting large metropolitan areas such as Dallas-Fort Worth, Houston, and the Austin-San Antonio Corridor, as well as statewide economic sectors including agriculture, industry, recreation, and tourism (TWDB, 2022). However, water availability of existing, traditional supplies in Texas is a growing concern as climate change causes droughts to intensify and become more regular, while population growth increases water demand. Specifically, between 2020 and 2070, the population in Texas is anticipated to increase by 73% to 51.5 million, with half of the growth expected to occur in the metroplexes of Dallas, Houston, and Austin (TWDB, 2022). This trend is reflected in a shift in water usage patterns: Historically dominated by agricultural needs, municipal demand is increasing.

Created in 1957, TWDB is the state agency responsible for ensuring Texas water security through three primary roles: (1) collect and share water data, (2) support regional water supply and flood planning, and (3) administer financial programs for water supply, treatment, flood management, and agricultural water conservation practices (TWDB, n.d.a). To accomplish these tasks, TWDB publishes state water plans on a 5-year cycle, each plan with a 50-year outlook (TWDB, n.d.d). Its goal is to ensure that, through regional water planning and best management practices—including conservation—the state will have sufficient water, even in a drought of record (TWDB, n.d.d).The term "drought of record" refers to a period in which natural hydrological conditions produced the lowest water supply on record, often coupled with high water use rates (TWDB, 2022). For much of Texas, the 6-year drought of the 1950s remains the most significant statewide drought and is considered the drought of record (TWDB, 2022). However, some regions in Texas have experienced more recent regional droughts of record that differ from the statewide benchmark. As such, regional water planning relies on these more localized data for planning purposes, ensuring that water supply can support peak water use despite exceptionally dry conditions (TWDB, 2021).

The 2022 Texas State Water Plan examined projected water demands, existing supplies, potential shortages, and strategy supplies and found that water demands are projected to increase by 9% between 2020 and 2070 (TWDB, 2021). Further, water user groups, categorized as irrigation, municipal, manufacturing, mining, stream electric power, and livestock, face a potential water shortage of 3.1 million acre-feet per year in 2020 and 6.9 million acre-feet per year in 2070 in drought-of-record conditions (TWDB, 2021).

According to the 2022 State Water Plan, if strategies are not implemented, approximately 25% of Texas' population in 2070 will have less than half the municipal water supplies they will require during a drought of record (TWDB, 2021). This projected increase in demand for municipal water supplies over the next 50 years is greater in proportion and total volume than any other water user group, rising from 5.2 million acre-feet per year in 2020 to 8.5 million in 2070 (TWDB, 2021).

Climate change is not considered in the 2022 State Water Plan, yet climate models project that Texas will experience drier conditions in the latter half of the 21st century, with an increase in precipitation intensity due to a warming Gulf of Mexico (Nielsen-Gammon et al., 2020). As a result of these factors, surface water will be negatively affected, increasing reliance on groundwater and depletion rates of aquifers (Mace & Wade, 2008). Currently, aquifers play a significant role in Texas water supply, providing groundwater for about 55% of the state's supply (TWDB, n.d.b). However, aquifers are increasingly vulnerable, as recharge rates, storage capacities, and flow regimes are highly variable due to climate change, over pumping, and land cover changes (Banner et al., 2010; Yoon et al., 2018).

Drought responses have and will likely continue to alter the water planning landscape. For instance, the 2011 drought challenged the Texas legislature on the municipal and domestic potable use of rainwater. Before this, aside from use in private residences, RWH could only be used for non-potable applications like irrigation (Combs, 2012).

RWH in Texas

Despite predicted erratic precipitation patterns, RWH can be a reliable water resource (Briones & Mace, 2025) and has growing regulatory support. Specifically, Texas allows the capture and use of RWH for potable purposes (Puig-Williams & Mace, 2019), while many local and state codes support RWH from site to commercial scales (TWDB, n.d.c). Municipalities and counties are encouraged to promote RWH at residential, commercial, industrial, and educational facilities through incentives such as discounts or rebates for barrels and water storage facilities, as outlined in Texas's Local Government Code (Rainwater harvesting, 13 Local Gov. Code § 580.004, 2013). For residents seeking to install these systems, the Texas Tax Code offers several financial incentives for RWH (e.g., Certain water conservation initiatives, 1 Tex. Tax Code § 11.32, 2001; Water-related exemptions, 2 Tex. Tax Code § 151.355, 2007), and homeowners' associations cannot prohibit the activity (Certain restricted covenants prohibited, 11 Prop. Tax Code § 202.007).

Furthermore, large-scale structures are also encouraged to install RWH systems. Texas House Bill (H.B.) 3391, passed in 2011, established important legal measures to promote RWH across the state. The law mandates that certain new state buildings must include RWH systems in their designs (Design standards, 4 Tex. Gov. Code § 447.004, 2013, (c-1), (c-3)). It also directed the Texas Commission on Environmental Quality (TCEQ) to develop regulations for using harvested rainwater for potable use when connected to public water systems (Standards for harvested rainwater, 5 Tex. Health & Safety Code § 341.042, 2013, (b)–(b-3)).

Texas H.B. 3391 added a provision to the Texas Local Government Code that is commonly known as the "rainwater harvesting code escape clause." This provision simply states that cities and counties cannot reject a building permit solely because the proposed structure will use RWH (Rainwater harvesting, 13 Local Gov. Code § 580.004, 2013, (c)). In other words, this clause prevents local governments from excluding RWH projects from the permitting process, thereby encouraging wider use of this water conservation practice throughout Texas (Tex. H.B. 3391, 82nd Leg., R.S., 2011; TWDB, n.d.c; Fancher, 2012). The circumstances, utilizations, and implications of these policies, however, remain infrequent to date (TWDB, n.d.c).

Although the 2012 State Water Plan did not recommend RWH as a water management strategy because the "volume of water may not be available during drought conditions" (TWDB, 2012), recent studies have found that RWH can be a dependable water source, even in drought conditions (Kim et al., 2015; Lawrence & Lopes, 2016; Briones & Mace, 2025). For example, to support the inclusion of this water management strategy in the state's water plan, Briones and Mace (2025) quantified the capabilities of RWH across Texas by calculating the firm yield. Firm yield refers to the demand for water that can be fully and reliably satisfied by the capture and storage of rainwater throughout drought-of-record conditions (Briones

& Mace, 2025). Additionally, the 2022 State Water Plan suggests that "about 5,000 acre-feet per year of supply from RWH strategies is recommended in 2070 to address needs" for select water users (TWDB, 2021, p. 109).

Given the tremendous need for supply strategies and the dependability of rainwater, cities, towns, universities, and the private sector are increasingly looking to implement RWH for potable and public use. For example, Austin—the capital city of Texas—has a large water utility, Austin Water, which serves over 1 million customers (Austin Water, 2018). In response to the 2008–2015 drought, Austin Water developed a water plan that covers a planning horizon of 100 years and includes climate change (Austin Water, 2018). Known as Water Forward, the plan includes lot-scale RWH as a supply strategy capable of capturing 1,550 acre-feet per year by 2040 if widely implemented (Austin Water, 2018). Scholars and practitioners have shown that in Austin, these systems are beneficial to the overall water supply as they reduce peak demands on municipal water supplies and utilities (Kim et al., 2015; Austin Water, 2018). Kim et al. (2015) found that RWH alleviates water shortages by increasing water availability and acting as a valuable stormwater management tool, increasing the overall resilience of the urban area and community. In fact, recent research on firm yields demonstrates that RWH is capable of meeting all indoor water demand requirements, i.e., potable and non-potable (Briones & Mace, 2025). However, a cost-benefit analysis determined that government subsidies would be necessary for potable single-home systems, though large-scale projects are economically viable (Kim et al., 2015). To mitigate costs, the City of Austin's RWH rebate provides up to $5,000 for purchasing RWH equipment for residential, multi-family, and commercial customers (Austin Water, 2018).

RWH is a viable path to a potable water resource, as no Texas law or regulation prevents a public water system (PWS) from using rainwater as a water supply. Indeed, the Texas Supreme Court states that once rainwater falls on a property owner's land or home, it is considered private property (Briones & Mace, 2025). Rainwater used for potable purposes in a single household—and importantly, not connected to a PWS—is not subject to regulation (TCEQ, 2012).

Alternatively, if the rainwater captured is meant to serve as a public water system, the rainwater is considered surface water by TCEQ for public drinking water purposes and must follow surface water regulations (TCEQ, 2012). The rainwater is then subject to the rules laid out in Title 30, Chapter 290 of the Texas Administrative Code (TAC), including operating requirements, monitoring, reporting, and more regulations under TCEQ. TCEQ defines a PWS as a system that supplies water for human consumption through pipes or other constructed conveyances and has at least 15 service connections or serves a minimum of 25 individuals at least 60 days out of the year (Definitions, 30 Tex. Admin. Code § 290.38, 2025, (73)).

To provide guidance, TCEQ published "Rainwater Harvesting: A Guide for Public Water Systems," which is an overview of necessary steps to obtain a permit for RWH for a potable public water system (TCEQ, 2012). Here, TCEQ describes design and construction requirements, including that TCEQ must be notified in writing of potential plans for potable RWH before beginning design and construction. Further, TCEQ's general collection and treatment criteria include sufficient capture capacity—including roof and storage—and a series of treatment technologies depending on the type of rainwater, generally involving filtering 99% of particles 3.0 microns or larger, a disinfection system capable of killing 99.99% of viruses, and sufficient storage capacity for treated water (TCEQ, 2012). These design aspects are further examined in this case study.

One Water approaches to water sustainability

One Water is an integrated holistic water resource management practice that values all sources of water as a resource and manages them as a single system within a specific geography, including drinking water, wastewater, stormwater, and grey water as one singular resource to be managed sustainably (Cardone & Howe, 2018; Puig-Williams & Mace, 2019). As freshwater sources dwindle and demand increases, Texans need to consider One Water strategies, such as RWH, water reuse, and other water conservation measures (Cardone & Howe, 2018). For example, replacing traditional toilets and urinals with non-potable water toilets or evaporative toilets can reduce the demand for total potable water by 25%–75% (Puig-Williams & Mace, 2019).

RWH supports this approach by reducing pressure on centralized systems and enhancing water supply reliability and stormwater capture efficiency (Shoja Razavi et al., 2024). Recent studies have examined RWH as a stormwater management tool, finding that it reduces runoff and lessens the burden on stormwater infrastructure (Carollo et al., 2022). Key metrics for evaluating RWH systems include stormwater control efficiency and water supply reliability, highlighting their value for augmenting water supply and managing urban floodplains (Shoja Razavi et al., 2024). Aside from collecting valuable resources, RWH also reclassifies stormwater as an asset instead of a nuisance. By decreasing runoff, improving water supply reliability, and aiding in flood prevention, it aligns with One Water approaches and promotes local, sustainable water management (Jamali et al., 2020).

Demonstrating how RWH can provide a sustainable, decentralized water source, the Campsite at Shield Ranch is the first TCEQ-regulated public water system in Texas to rely entirely on rainwater capture for the facility's potable water supply needs. The Campsite provides evidence that, even at the scale of public water systems, rainwater can be harnessed to meet

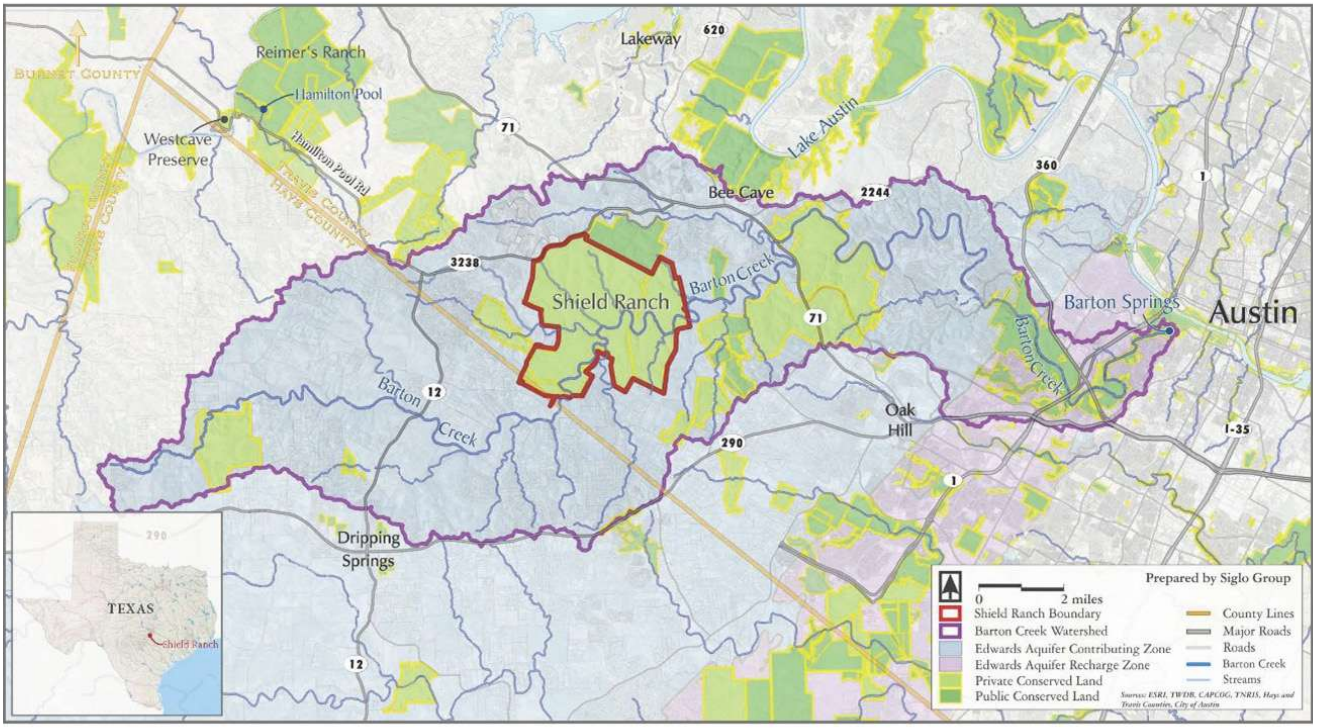

Figure 1. Location of the Campsite at Shield Ranch in relation to Texas, USA. Map courtesy of Shield Ranch.

potable water needs. As Texas continues to adopt One Water strategies, projects like the Campsite set a precedent for how RWH can be an integral part of a durable water future.

CENTRAL TEXAS: URBAN GROWTH AND WATER SCARCITY

As previously noted, population growth in Texas is expected to increase unequally, with projections showing that growth will concentrate around the state's metropolitan areas, including Austin, Dallas-Fort Worth, Houston, and San Antonio (TWDB, 2022). The Austin metroplex, encompassing Travis County and surrounding regions, has experienced significant population growth in recent years (U.S. Census Bureau, 2023). The population of the Austin–Round Rock area was estimated to exceed 2.3 million people in 2022, with Travis County housing 1.3 million residents (U.S. Census Bureau, 2023).

Currently, Austin's drinking water is sourced from the Highland Lakes of the Lower Colorado River, managed by the Lower Colorado River Authority (LCRA; LCRA, n.d.). Dammed upstream from Austin, the Colorado River forms the Highland Lakes: Lake Buchanan, Lake Travis, Inks Lake, Lady Bird Lake, Lake Lyndon B. Johnson, Lake Marble Falls, and Lake Austin. Lake Buchanan and Lake Travis act as the region's water supply (LCRA, n.d.). Water for Austin is treated by three major water treatment plants; wastewater is treated by two major plants (Austin Water, 2018). Water availability is mostly dependent on rainfall, inflows, and LCRA's management of the water in Lake Travis and Lake Buchanan (LCRA, n.d.). In 1999, the city contracted with the LCRA through a state-approved run-of-river water right and a water-supply contract, which granted the city access to water during a repeat of the drought of record (Austin Water, 2018). Instead of the statewide 1950s drought, LCRA and the Lower Colorado River Planning Group use the more recent drought of record, the 2008–2016 drought, as a new regional benchmark (TWDB, 2022).

Growth in this region is expected to continue, with population projections indicating an increase of roughly 50% by 2050 (Capital Area Metropolitan Planning Organization, 2025). According to the 2022 State Water Plan, this rapid increase is driven by economic opportunities and a strong job market (TWDB, 2022). With the expanding population, water demands in the Austin Metroplex have grown substantially (TWDB, 2022). The 2022 State Water Plan highlights an increase in water consumption and the need for effective management of current surface and groundwater sources to meet future demands (TWDB, 2022). The plan also prompts Texans to invest in water infrastructure development, providing reason to continue exploring and implementing RWH systems as part of a comprehensive One Water approach.

Study site: The Campsite at Shield Ranch

Shield Ranch was founded in 1938 when Fred and Vera Shield purchased land on Barton Creek in Southwest Travis County (Figure 1; Shield Ranch, n.d.a). Fred Shield, an

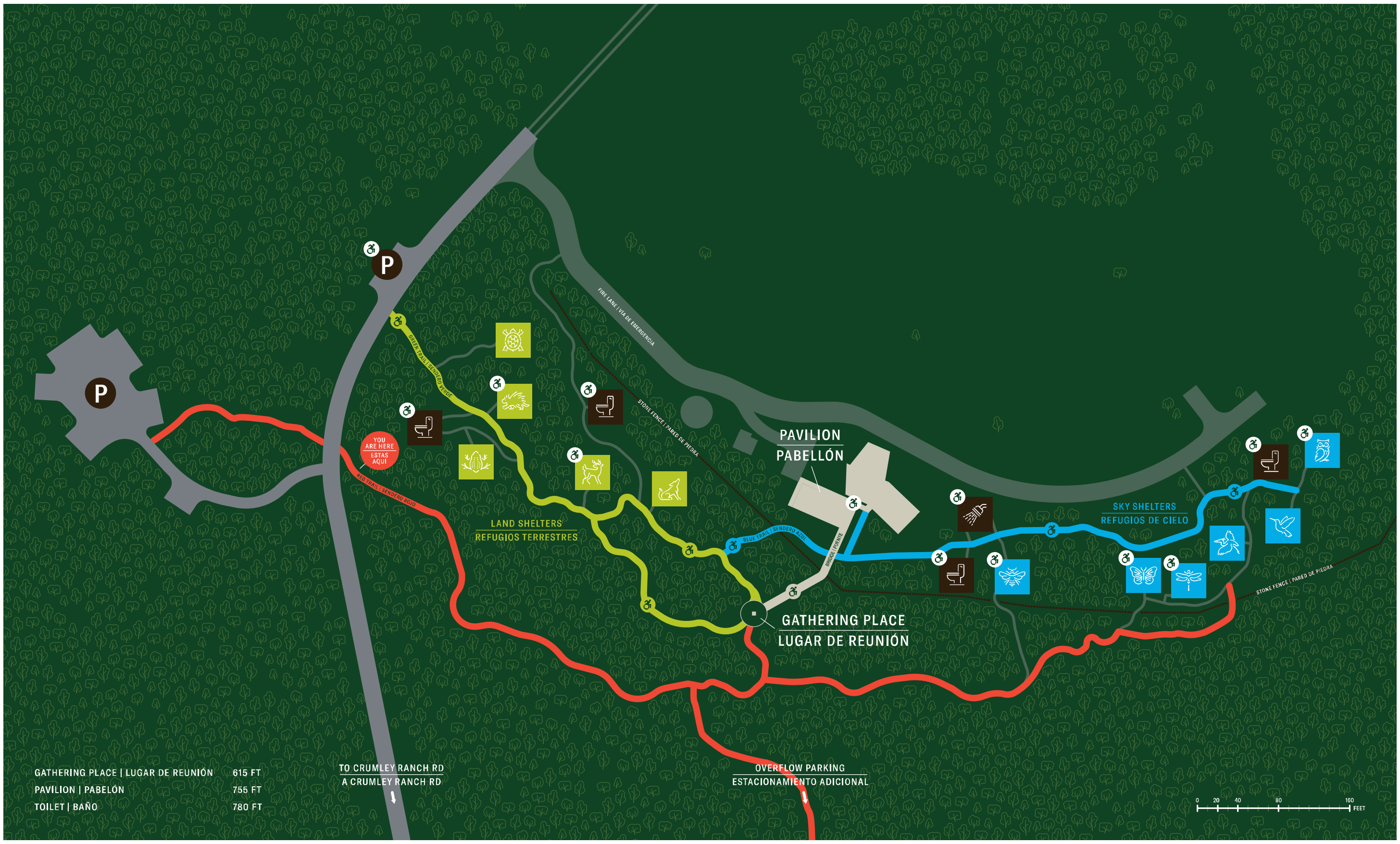

Figure 2. Layout of the Campsite at Shield Ranch: A series of shelters surround the Horizon Hall at the pavilion. Design by Asterisk.

independent oil producer and wildcatter, and Vera Shield, a nurse anesthetist, were both passionate about the outdoors and loved to share their ranch with their family and friends (Shield Ranch, n.d.b). Stewardship of the 6,600-acre ranch lies with the Shield-Ayres-Bowen family, who carry out an extensive land stewardship and management program set out to benefit the ranch's rangelands (Shield Ranch, n.d.b). The rangeland improvement program includes woody species management, rotational grazing, prescribed burning, and wildlife management, which helped improve the biodiversity and ecological health of the land (Shield Ranch, n.d.b).

During the late 1990s, the Shield-Ayres-Bowen family placed most of the ranch in conservation easements with The Nature Conservancy and the City of Austin (Shield Ranch, n.d.b). These legally binding conservation easements permanently protect the ranch's water quality in Barton Creek, the open rangelands, wildlife habitat, and natural and cultural resources (Shield Ranch, n.d.b). These conservation easements preclude residential subdivisions and commercial development but allow the owners to construct limited facilities for non-profit use while also continuing traditional activities such as ranching, hunting, and recreation (Shield Ranch, n.d.b).

The vision of Shield Ranch is "to connect people more deeply to the natural world and thus to themselves and to their community" (Shield Ranch, n.d.c). Their mission is to "steward and share Shield Ranch in ways that educate, inspire, and transform" (Shield Ranch, n.d.c). Stewardship, sanctuary, and community are values that Shield Ranch is committed to upholding (Shield Ranch, n.d.c). Their mission and values are achieved through their efforts to restore the land by practicing natural resource management, protecting resources, participating in advocacy and engagement in regional issues, fostering research and education, instilling a sense of community, and creating a sacred space and refuge for communities seeking to broaden and deepen their relationship with nature (Shield Ranch, n.d.c).

The Campsite at Shield Ranch—"Where Community and Nature Meet"—is a 100% off-grid, sustainably built campsite that demonstrates their commitment to conservation (Shield Ranch, n.d.c). The Americans with Disabilities Act (ADA)-compliant Campsite offers several fully accessible facilities (Figure 2), including sleeping shelters (Figure 3), for Camp El Ranchito—a nature-immersion youth camp—and nature connection experiences for groups focused on environmental values, education, and philanthropy (Shield Ranch, n.d.c).

Figure 3. Sleeping shelter at the Campsite at Shield Ranch. Photo by Brian Fitzsimmons.

Figure 4. The pavilion at the Campsite at Shield Ranch. Photo by Leonid Furmansky.

The 11 sleeping shelters range from 310 to 490 square feet with a total sleeping capacity of 74 (Shield Ranch, 2021). Constructed with a minimal environmental footprint, the shelters are made of cedar and steel and have minimal interior furnishings and no electrical outlets. Outhouses equipped with evaporative toilets and handwashing stations using rainwater are located in close proximity to the shelters. Near the two-story pavilion, a central location for all campers and guests, there is a shower building that utilizes rainwater.

Groups convene at Horizon Hall at the pavilion (Figure 4), a second-story 1,800 square foot space with an adjacent commercial kitchen. The space is equipped with technology (such as speakers, microphones, and Wi-Fi capabilities) for large group meetings, bathrooms with traditional flush toilets, a weather room, office spaces for staff, and a solar-powered elevator. Using a nature-based and low-impact design, the space is cooled by fans and screens in the warmer months and heated by a fireplace and a wood-burning stove in the cooler months.

SUPPLIED BY THE SKY: WATER AND ENERGY AT THE CAMPSITE

In 2007, the Shield Ranch Foundation, a non-profit 501(c)(3) private operating foundation, was established along with the nature-immersion camp named El Ranchito (Shield Ranch, 2021). The camp's original temporary structures included tents, a pop-up outdoor kitchen, portable showers, handwashing stations, portable toilets, and an off-site emergency shelter located off the ranch (Shield Ranch, 2021).

Challenges of inaccessible municipal water supply and local groundwater wells drying due to over pumping of the local aquifer, combined with the Ranch's commitment to environmental stewardship, prompted leaders to explore low-impact designs, RWH, and solar power—resulting in the 100% off-grid campsite seen today (Shield Ranch Foundation, 2024). Ranch staff contemplated various other low-impact solutions, such as atmospheric water generators, on-site water reuse systems, composting toilets, raised beds for greywater, and aerobic wastewater systems, but these options were not attainable due to location, environmental constraints, permitting challenges, and/or cost. In the following sections, we describe these low-impact designs, including the water and energy systems, and their functionality, regulatory landscape, and existing metrics available at the time of this writing.

Water

The Campsite at Shield Ranch derives all potable water for drinking, handwashing, cooking, and showering from RWH. Rainwater is collected from the roofs of the pavilion and the shower building. The total catchment area equals 7,340 square feet with the potential to collect 4,575 gallons of water for every inch of rainfall. The rainwater is stored in two 30,500-gallon reservoirs and two 3,400-gallon cisterns, equaling a combined storage capacity of 67,800 gallons. One of the 3,400-gallon cisterns stores treated rainwater, while the other stores raw rainwater. The treatment process consists of sediment and pathogen filtration and chlorination.

In addition to the potable use reservoirs, there are three on-site water storage reservoirs with a combined storage capacity of 73,800 gallons located along the fire lane. A large 67,000-gallon reservoir and two satellite tanks, each with a capacity of 3,400 gallons, make up the total storage capacity. These reservoirs are dedicated solely to the fire suppression sprinkler system in the pavilion and the fire department per local fire code requirements. These tanks are required to remain at a minimum of 95% capacity. The static water in the fire tanks was originally trucked in to initiate construction of the Campsite. Now, the water from these tanks is mostly used for fire department inspections and is refilled with reuse water (from the RWH PWS line flushing when testing chlorine residual).

Permitting process and considerations for the first rainwater-sourced PWS

Guidance for public water systems and their regulations is provided in Title 30, Chapter 290, of the TAC (TCEQ, 2012). TCEQ has adopted these regulations for administering public water systems, including those that provide rainwater as potable water. The regulations ensure that public water systems are designed and constructed properly to achieve flow rates that meet the system's needs (Rules and regulations for public water systems, 30 Tex. Admin. Code §§ 290.38–47; TCEQ, 2012). This includes collection, treatment, storage, and distribution facilities.

TCEQ evaluates the design and size of each system on a site-specific basis (TCEQ, 2012). However, general regulations and guidelines apply to all systems. For example, TCEQ requires that the roof capture area and storage tank are large enough to retain an adequate supply during all seasons (TCEQ, 2012). Furthermore, TCEQ requires a PWS, including systems that utilize RWH, to monitor for more than 100 different water quality constituents and other contaminants that could be introduced during collection and storage (TCEQ, 2012), regardless of the water source. The complete list of regulated contaminants and chemicals as well as their testing and monitoring requirements, is provided in Title 30, Chapter 290 of the TAC (Drinking water standards, 30 Tex. Admin. Code §§ 290.101–290.122). In addition to these, organic and inorganic chemicals, total organic carbons, coliform bacteria, lead, copper, and disinfection by-products are tested in disinfectant and turbidity monitoring (TCEQ, 2012). Specific treatment technology is required by TCEQ to achieve the potable water requirements:

- A filter capable of removing 99% of particles 3.0 microns or larger in diameter;
- A chlorine disinfection system that can inactivate or kill 99.99% of viruses that could be present in the untreated rainwater (Note: TCEQ does not allow systems with water conveyance to receive ozone or UV treatment due to the requirement of maintaining a chlorine residual through the distribution system.); and
- A disinfection system large enough to treat an adequate amount of water to meet the maximum daily needs throughout the year (TCEQ, 2012).

Storage, pressure maintenance, and the distribution system materials and construction must be rated to potable water standards, and the distribution facility must meet both the American Water Works Association and TCEQ standards (TCEQ, 2012). Additionally, it is required that water be disinfected before it enters the treated-water storage tank. The distribution facility must be capable of distributing an adequate supply during peak demand times throughout the year (TCEQ, 2012). Meanwhile, the minimum capacity requirements for providing adequate quantities of potable water and alternative capacity requirements for site-specific demands are found in the TAC (Minimum water system capacity requirements, 30 Tex. Admin. Code § 290.45, 2025; General provisions, 30 Tex. Admin. Code § 290.39, 2023, (I)). The supervision of a water operator who holds a Class C or higher surface water license must oversee the monitoring, reporting, and treatment of the water (TCEQ, 2012). A Class D operator can perform most daily operations under the supervision of a Class C operator (TCEQ, 2012).

TCEQ requires that the operator monitor turbidity, pH, temperature, disinfectant residual, and chlorine residual at least once a day, and the operator must submit a surface water monthly operating report (TCEQ, 2012). A complete record of operations, a monitoring plan, an operations and maintenance manual written by the operator and engineer, a corrosion control program, and a supply of parts, equipment, and reagents for backup are also required for system operation (TCEQ, 2012).

According to TCEQ, the Campsite RWH system is considered a transient, non-community water system, or a public water system that is not a community water system but serves at least 25 people at least 60 days out of the year (Definitions, 30 Tex. Admin. Code § 290.38, 2025, (86)). A community water system qualifies as a PWS when it has the potential to serve 15 residential service connections or more on a year-round basis or serves at least 25 residents on a year-round basis (Definitions, 30 Tex. Admin. Code § 290.38, 2025, (17)). Meanwhile, a transient system does not continuously provide water for people year-round, thus qualifying the Campsite at Shield Ranch as a non-community water system.

TCEQ initially provided a conditional permitting process for the Campsite to address the water sources, the cartridge and pathogen filtration, the roof slope, and storage tanks, including the following requirements:

1. A contract with a TCEQ-approved public water hauler must be put in place so that if there is insufficient rainwater, water can be trucked in to meet the maximum daily demand at 42 gallons per person per day.
2. If the RWH PWS fails to provide sufficient supply, the Campsite must be closed until sufficient supply is met.
3. Diverted rainwater for potable use and the area where it is stored shall be evaluated and protected from sources of contamination.
4. The Campsite shall provide TCEQ with specific water quality parameters of the rainwater harvested such as pH, total coliform, and turbidity.
5. The rainwater must be monitored for microbiological water quality, e.g., *E. coli* testing every two weeks, and long-term enhanced surface water treatment must begin once the PWS is constructed and distributing water.

The filtration conditions address the removal of particles and pathogens such as *Cryptosporidium* and *Giardia lamblia* with the filtration being site-specific. All distributed water must first be treated by cartridge filters, which are 100-, 20-, and 1-micron particle filters followed by a 1-micron pleated-style pathogen filter. At least once daily, the pressure at the inlets of the filters and the pressure differential across the filters must be monitored and recorded. Additionally, a qualified operator must be present when any repairs or changes are made, unless the plant is equipped with continuous monitors, alarms, and shutdowns.

The permit conditions regarding the ground storage tank and the roof slope state that the storage tank must be inspected annually. The inspection is to determine if:

- the tank is in watertight condition;
- the vents are properly in place;
- the roof hatches are closed and locked;
- the flap valves and gaskets are adequate;
- the interior and exterior liner system is providing adequate protection; and
- the instruments and controls are working properly.

Additionally, maintenance and inspection records must be retained for at least 5 years. Although the Campsite's conditional permit was designed to monitor and treat the RWH system 365 days per year, the Campsite sought clarification from TCEQ in 2024 on how this schedule may be revised when the system is not producing water and/or shut down during their annual fallow period or a significant freeze event. TCEQ con-

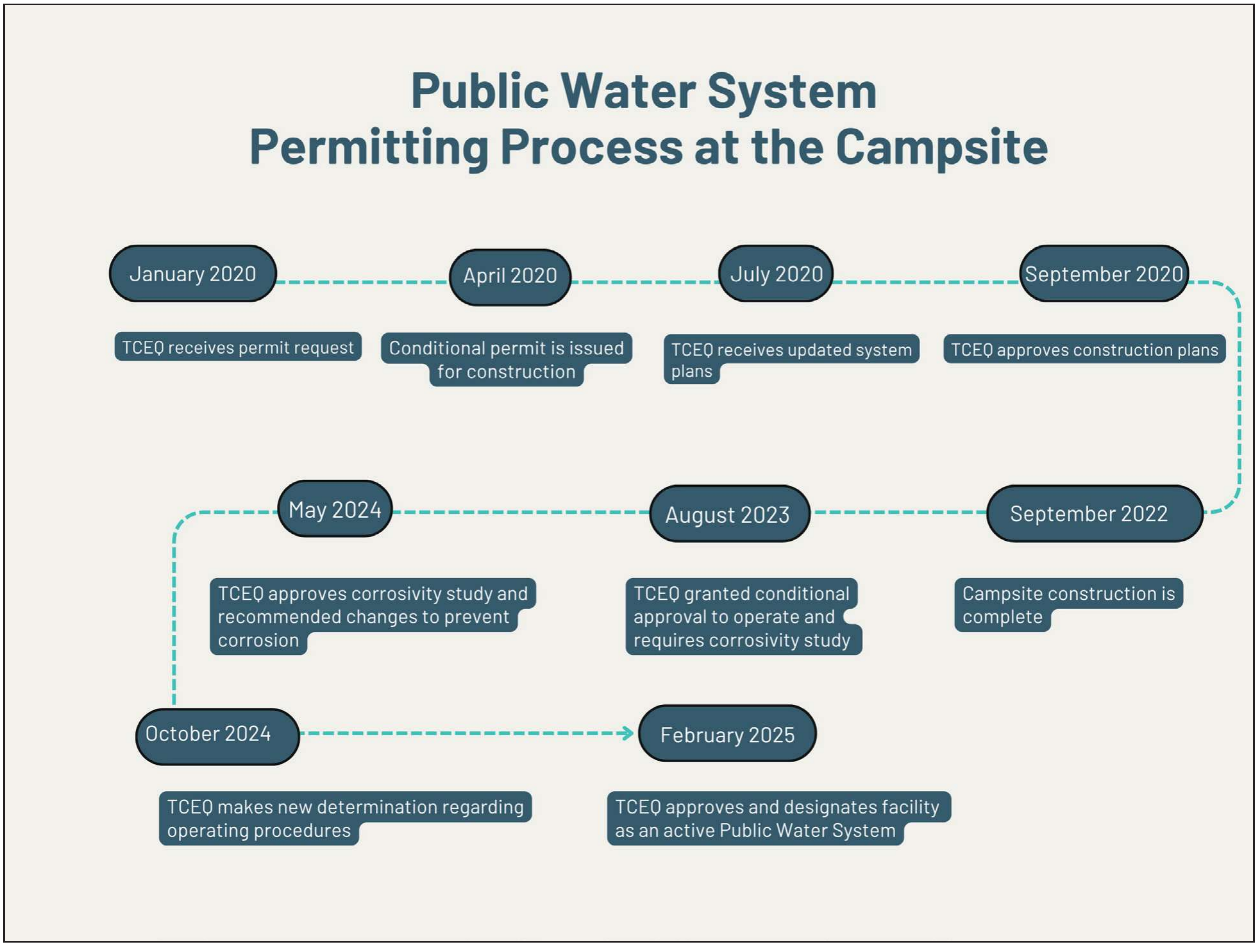

Figure 5. The Campsite at Shield Ranch's public water system permitting process timeline.

firmed that the only necessary modification to the monitoring plan would be to document the time that was spent offline and collect a special sample before returning to operation. During a low-water usage partial shutdown when no water needs to be produced, monitoring and flushing in the distribution systems remains the same, but the treatment plant does not need to be run, only documented as offline. At this time, the Campsite also received approval to operate the treatment plant as needed during normal operations, with daily monitoring of distribution residuals and adding chlorine when necessary. These modifications were a significant step forward for system efficiency and associated operations cost savings. The distribution pumps are never to be turned off to ensure constant pressurization of the system. A broad overview of the permitting process is displayed in Figure 5.

Rainwater-sourced PWS design

The PWS at Shield Ranch (Figure 6) begins with the collection of rainwater from the 7,340 square feet catchment area, or total roof area, which collects approximately 4,575 gallons from a 1-inch rain event. Gutter guards are in place to prevent debris from entering the system. The collected water is then stored in a 3,400-gallon and two 30,500-gallon "raw water" tanks. Raw water, or untreated rainwater, can be acidic and therefore corrode plumbing fixtures. To prevent corrosion, a pH-balancing solution (sodium hydroxide) is added prior to the full treatment process to neutralize the water. The raw water is then transported from the storage tanks to the treatment room through an underground pipe connected to two alternating pumps.

A water meter installed on the intake pipe at ground level measures the incoming raw water volume in gallons. This value is monitored and recorded daily. As the water is pumped to the filters, it flows through a pre-filtration turbidity meter that measures raw water clarity by detecting small, suspended particles. The raw water then passes through three sediment filters at 100-, 25-, and 1-microns, targeting large to small particulate matter, removing 99% of particles 1 micron or larger. A fourth filter, a pleated filter Cartridge HC/170-LT2 by Harmsco, or a pathogen filter, removes microscopic organisms, such as *Cryptosporidium* and *Giardia lamblia.* After the water is

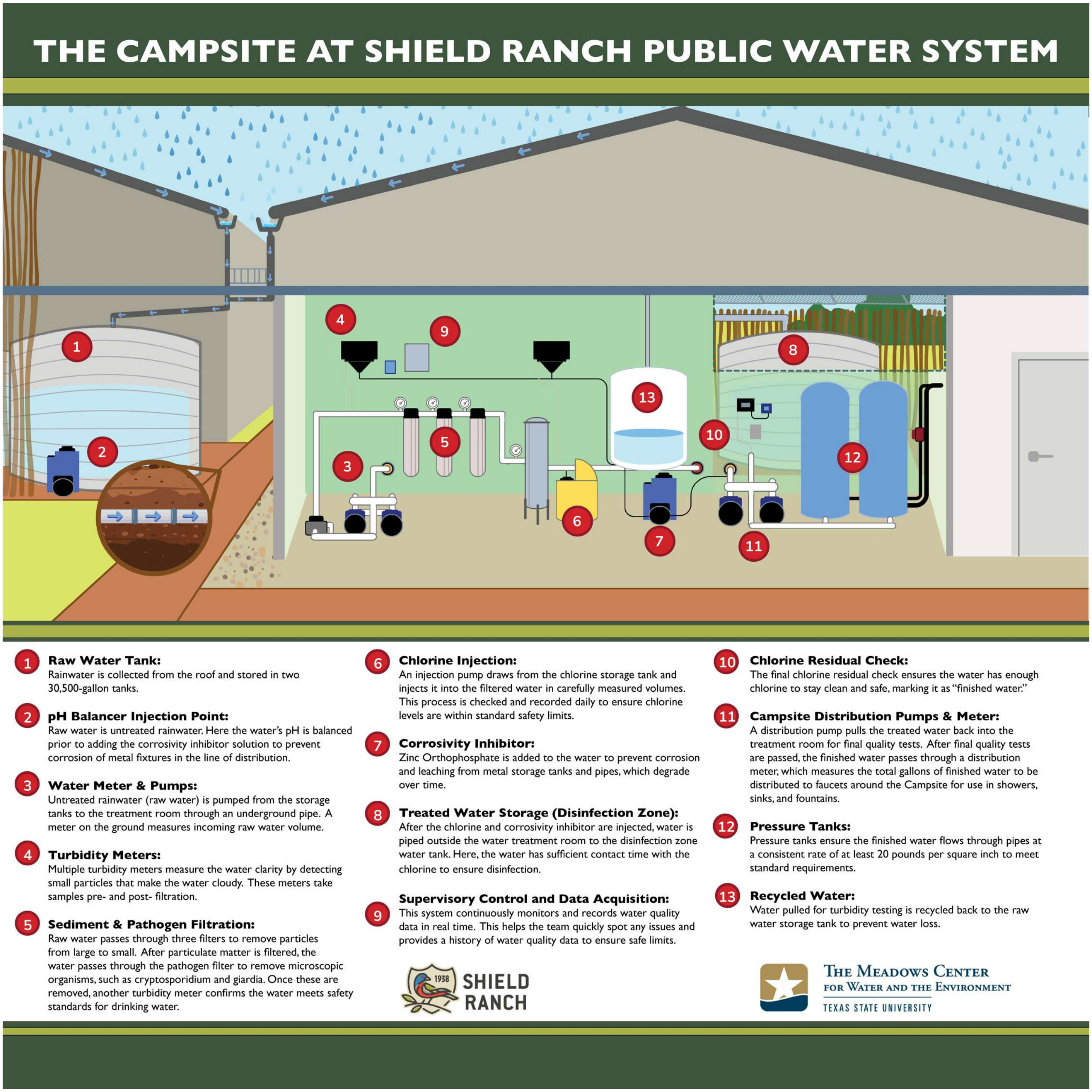

Figure 6. The Campsite at Shield Ranch's rainwater capture, storage, treatment, and distribution processes. Graphic created by Sarah Wingfield.

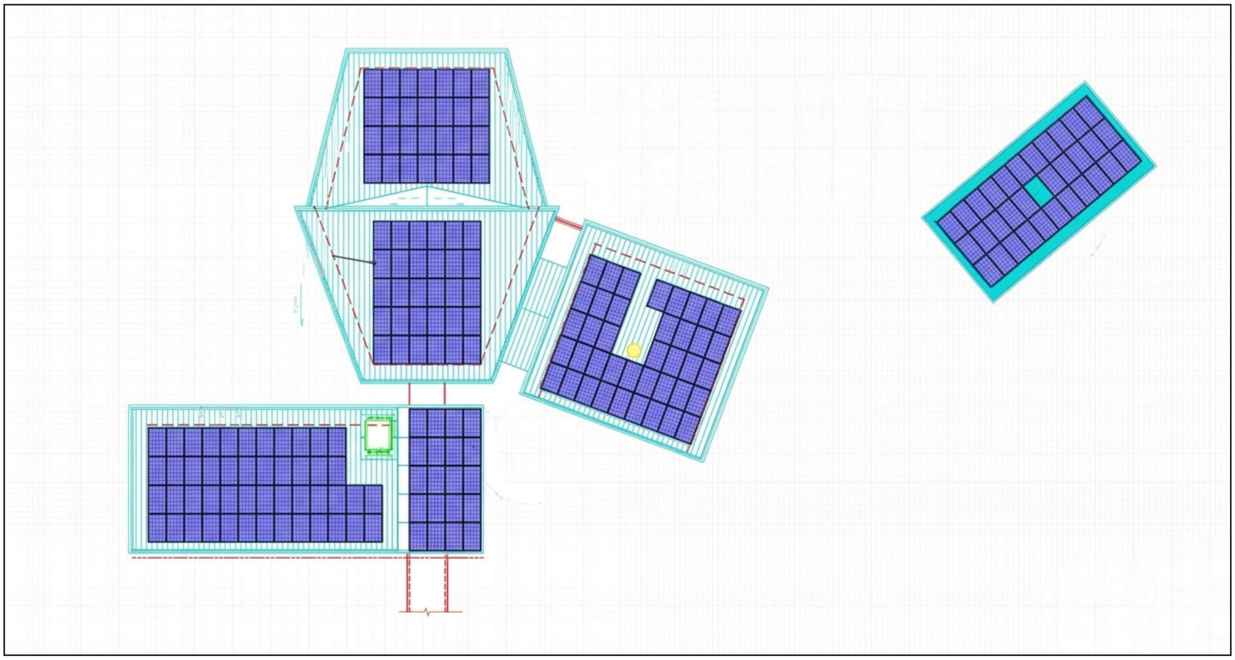

Figure 7. Pavilion building rooftop solar layout. Designs courtesy of Shield Ranch.

filtered for sediment and pathogens, a post-filtration turbidity meter confirms the water meets TCEQ standards for drinking water: Post-filtration water must not exceed 0.3 nephelometric turbidity units (NTU). At this stage, chlorine is added to the water. An injection pump draws chlorine from a 10-gallon storage tank and injects it into the filtered water in precise amounts for disinfection. This process is checked and recorded daily to ensure chlorine levels meet TCEQ's standard of a minimum chlorine residual of 0.25 milligrams per liter (mg/L). Before reaching the disinfection zone, zinc orthophosphate is added to further prevent corrosion and leaching in plumbing fixtures, balancing the treated water's pH to safety standards.

Once the chlorine and corrosivity inhibitor are injected, the treated water is piped outside the treatment room to the 3,400-gallon disinfection zone water tank. The disinfection zone ensures that the water has sufficient contact time with the chlorine for adequate disinfection. A Supervisory Control and Data Acquisition (SCADA) system continuously monitors and records water quality in real time, which provides a history of data to maintain safe drinking water and assists the system operator in monitoring for safety issues. A final chlorine residual-check system ensures the water remains clean and safe for drinking, marking it as "finished water."

Distribution pumps pull the finished water back into the treatment room for final water quality tests. Once the water meets its final quality check, the finished water passes through a water meter, measuring total gallons of finished water produced for distribution. The distribution pumps are attached to two water pressure tanks that guarantee a consistent pressure of at least 20 pounds per square inch. Finally, the distribution pumps supply finished water throughout the Campsite for use in showers, sinks, and drinking fountains.

Water is regularly sampled for chlorine residual at the furthest points in the distribution system (i.e., handwashing stations at the four outhouses). If the chlorine residual is below the minimum concentration, the water will be flushed to allow "fresh" finished water to enter the waterlines at these furthest points. TCEQ mandates that all water, out to the furthest point in the distribution system, maintain a minimum chlorine residual of 0.25 mg/l. As such, given the Campsite's extremely low and intermittent water usage, water must be flushed through the system often. The amount of water flushed during this process and the chlorine residual readings are recorded daily. This flushed water is collected and used to replenish water in the fire suppression storage tanks.

As a final note on system design, the RWH system does not have a first flush diverter. In this system, the "diversion" of large particles from the roof is accomplished by utilizing high-quality (small mesh) gutter screens. Once water passes through the screens, the fine sediment either settles out in the large storage tanks or gets filtered once it goes through the three sediment filters.

Energy

Electricity for the Campsite at Shield Ranch, including power for the PWS, is fully provided via an on-site solar microgrid that is located on the roofs of the pavilion and shower buildings, the same structures that collect rainwater (Figure 7). The microgrid consists of generation through solar panels, a battery energy storage system, and a distribution system to the

Figure 8. Aerial view of the Campsite at Shield Ranch. Photo courtesy of Hill & Wilkinson.

Campsite's facilities. The solar panel array is made up of 198 sixty-cell photovoltaic panels located on the roof of the main building, the pavilion, and the shower building (Figures 7 and 8). Twenty architectural panels are mounted above the foyer of the pavilion to allow dappled light in, while the remaining panels are on the roofs. The panels convert sunlight into 67 kilowatts of direct current to the microgrid.

The lithium-ion batteries used to store the energy allow for 102 kilowatt-hours of storage. Out of sight, the battery energy storage system (BESS) unit houses 27 lithium batteries and has safety features, such as climate control with air conditioning, heating, and fire and sound suppression systems. In the event of system failure, a 60-kilowatt propane-powered generator is onsite and will automatically turn on when the storage drops to or below 20%. The generator will then charge the batteries to 40% and automatically shut off. During 2023, the Campsite produced 48,286 kilowatts of electricity from its solar panel microgrid, enough energy to charge 14.3 electric vehicles and power 4.5 homes per year (Shield Ranch Foundation, 2023).

Permitting process and considerations for the PWS's energy source

The solar installation process did not require specific permitting. However, the fire department required certain measures for safety. Because the Campsite is fully off grid, the fire department mandated a diesel-powered engine and pump to charge the pavilion's fire suppression sprinkler system in the case of a fire and a backup generator in case of a power failure. Likewise, TCEQ requires a backup power source to operate the PWS so that water service is maintained at 20 pounds per square inch (psi) during a power outage lasting more than 24 hours.

WATER CONSERVATION MEASURES AND CONSIDERATIONS

As all water for the Campsite is harvested on-site, water conservation considerations are embedded in the system, within the educational messaging to users, and the ethos of the staff. In addition to being the first permitted rainwater-sourced PWS, the Campsite was also the first to be permitted by TCEQ to use waterless toilets. In the following section, we describe the water reduction and reuse methods as well as the educational component that has become an indelible aspect of being a Campsite user.

Water reduction

The Campsite's septic facility is the first on-site facility permitted by Travis County and approved by TCEQ that utilizes evaporative waterless toilets. The evaporative toilets serve as a TCEQ pilot project and provide a model for others seeking approval for low-impact, waterless toilets within Texas. Two to three evaporative toilet units are integrated into each outhouse structure (Figure 9). These structures are made of cedar and steel with concrete floors. The four outhouse structures throughout the Campsite are ADA accessible, and each has a handwashing station that uses rainwater from the on-site PWS system. Each stall has an overhead light and a switch to operate an exhaust fan that uses low-voltage power from the solar microgrid. All faucets, including the showers, are on a timer, e.g., once pushed to turn on, they automatically turn off after about 7 seconds.

Figure 9. The Campsite outhouse complex containing three evaporative toilet systems. Photo by Blake Murden.

The evaporative toilet is a low-maintenance human waste system with minuscule site disturbance infrastructure that is a low-cost alternative to a traditional on-site septic system. Evaporative toilets differ from the traditional Clivus Multrum composting toilets that typically require a deep vault with odorous microbial breakdown-composting of the waste and periodic pumping. For the evaporative toilets, dehydration and evaporation reduce the waste to a neutral and odorless dry ash material (SWSLoo, 2022). This process uses solar radiation and airflow to evaporate liquids and desiccate solids, eliminating pathogens through a natural biological process. However, not all on-site Campsite toilets are waterless. The flush toilets were included in the design of the pavilion to accommodate safety regarding elderly or limited-mobility users, eliminating the need to traverse outdoors away from the large meeting room at night to use an outhouse.

The wastewater produced at the pavilion and the shower station is treated by a high performance biofiltration system, utilizing an on-site subsurface drip dispersal field. The process removes nitrogen from the used water, a process that helps protect the area's water resources.

Permitting process and considerations for the waterless toilets

While the Campsite's permitting authority was Travis County, Shield Ranch staff chose to first seek approval of the project from TCEQ and then communicate to Travis County commissioners of the agency's support of the groundbreaking system. Because evaporative toilets are not specifically listed in Travis County rules, the Campsite evaporative toilet system is required to meet specific criteria to receive a code variance:

- The system's manufacturer must conduct or approve the installation of the units, preventing malfunctioning due to improper installation.
- An alarm must be installed on the units to sound when the predetermined liquid level is reached in the lower chamber.
- The vent pipes are required to be taller than the building.
- Any personnel or staff who conduct work or maintenance on the units must have documented training or certification.

- Records of the installation, initial operation date, trained employees, waste levels, atmospheric conditions, removal amounts and dates, number of users, and any conditions that indicate the units are not properly operating must be kept in a log on-site and readily available for inspection.
- Finally, if the units ever become a nuisance or a public health hazard according to TCEQ or Travis County, they may be revoked of permitting and cease use or be removed.

As of 2024, TCEQ does not have the ability to approve evaporative toilets statewide, and on-site sewage facilities must be tested over a period of 6 months (On-site sewage facilities, 30 Tex. Admin Code §§ 285.1–285.91). Currently, no technology exists to directly test evaporative toilets because their performance depends on physical processes like cloud cover and temperature.

Water reuse

The Campsite staff prioritize water conservation by reusing water where possible. Some examples of this include reusing water from system maintenance. During the final treatment phase, about 120–190 gallons of water flowing through the system are tested for turbidity and chlorine residuals before distribution, and the water from the turbidity testing is recycled back into the raw water tanks. Also, the process of flushing the entire system to maintain chlorine residual water quality standards requires roughly 40–60 gallons of water. This water cannot be returned to the water system but is still collected and used for small-scale irrigation and to refill the Campsite's fire-suppression tanks, which must be at least 95% full at all times.

Water conservation education

All visitors to the Campsite receive an orientation from staff about the facilities and off-grid systems with an emphasis on the importance of energy and water conservation. During camp, staff show campers their water use over a 24-hour period each morning using a whiteboard. Throughout the camp season, each camper goes through water education sessions, learning about the water cycle. They also attend presentations and participate in hands-on activities that are designed to teach water science. Through their education and daily water-use monitoring, campers used about 12 gallons per person per day (Shield Ranch Foundation, 2024; Shield Ranch Foundation, 2023), while the average Texan uses about 87 gallons per capita (Water Conservation Advisory Council, 2024).

OUTCOMES AND METRICS: WATER AND ENERGY SAVINGS

Since operations began in 2023, water usage and user data are collected monthly by the Campsite staff for monitoring. The data varies throughout the year based on use, demand, and maintenance of the system to meet the standards for public water systems. For example, the month of August is typically a fallow period for the Campsite. Although there were zero users during this time in 2023, regulatory procedures to maintain the standards of a PWS resulted in daily water usage (Shield Ranch Foundation, 2023). To meet these standards, the system is monitored 365 days a year, regardless of the number of users.

At the time of this writing, the Campsite has operated fully on rainwater and has not needed to supplement water supply with an external source. In 2023, the Campsite used 43,790 gallons of water and had a total of 3,306 users, roughly translating to about 12 gallons of water per user. In the second operation year (2024), 69,230 gallons of water were used to support 3,693 users, equating to 19 gallons per user. Figure 10 displays usage by month for 2023 and 2024.

Calculating the exact gallons per capita is difficult because of the various constraints of maintaining a transient, non-community public water system. For one example, as mentioned August is a generally a fallow month for the Campsite with zero users. However, water is still used. It is reasonable to assume the system should be shut down when there are zero users; however, the shutdown procedure for the system requires draining all water lines, turning off the pumps, and locking the system. Once the system is turned back on, all pipes require disinfecting, requiring the operator or a contractor to flush the system with high concentrations of chlorine. This approach was not feasible for the Campsite, as it was impossible to shut off sections of the system until October 2024 when TCEQ declared that the water supply did not need daily treatment. This change allowed the operator the ability to treat water only as needed to maintain adequate levels in the finished water tank. Also, the total gallons used for both years accounts for all water usage, including flushed water, and the water quality test performed prior to distribution.

DISCUSSION

The Campsite RWH case study offers broader implications for water management and technical insights through lessons learned. First, considering the scalability of RWH systems, this public water system qualifies as a transient, non-community water system. Therefore, this PWS is not a community water system but serves at least 25 people for at least 60 days out of the year (Definitions, 30 Tex. Admin. Code § 290.38, 2025, (86)). This PWS has been able to supply 100% of their source water needs from RWH.

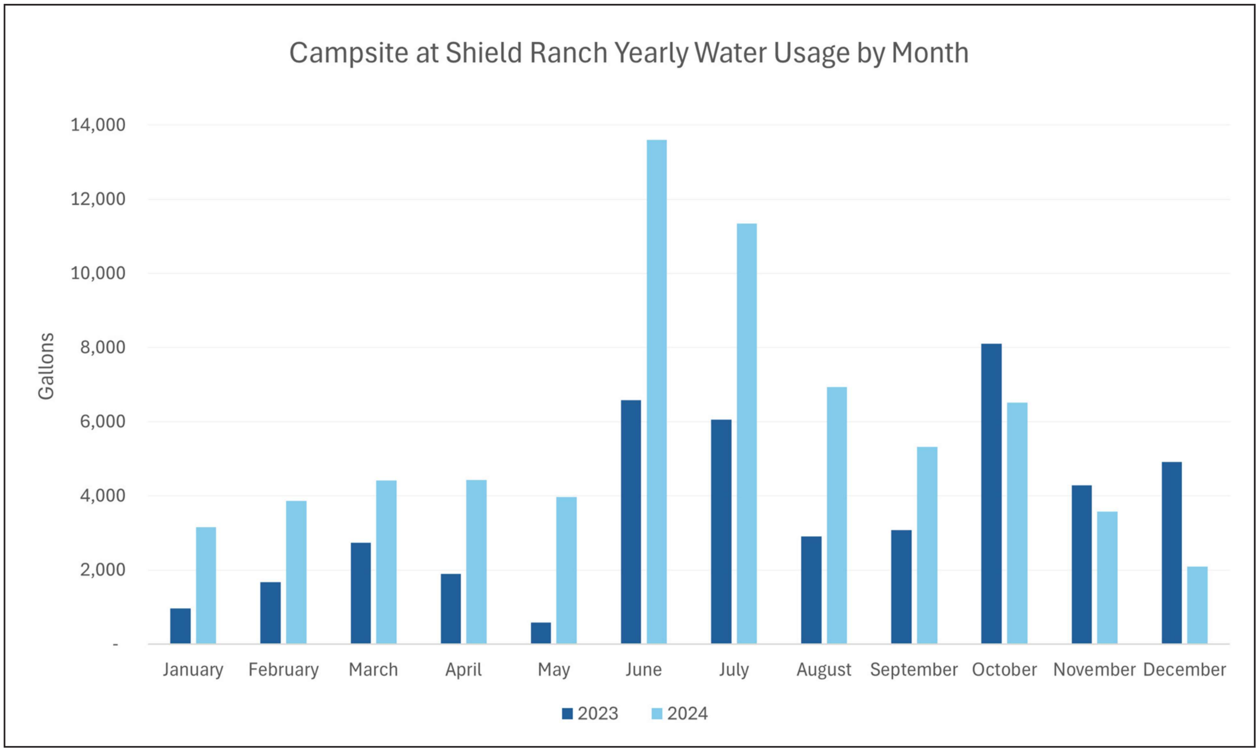

Figure 10. The Campsite at Shield Ranch's yearly water usage by month.

For the purposes of the pilot project at the Campsite, the system demonstrates the viability of decentralized water solutions through proof of concept in water-challenged regions such as Central Texas. Although there are variabilities in rainfall patterns in the region, the Campsite has not needed to truck in water since opening, and the installation of the evaporative toilets has proven to be a success. Their efficiency, along with minimal maintenance and zero water use, has boosted their on-site water security.

The Campsite's experiences in being the first to navigate RWH policy and regulation highlight the need to update codes and streamline permitting processes due to the regulatory challenges. After a few years of operation at the Campsite, there are notable changes through technical insights, lessons learned, and updated permit requirements. Reflecting on the water treatment room design, the room faces spacing constraints. Future designs for these decentralized treatment rooms should allocate additional space for bench-top water sampling and testing equipment, filter and chemical storage, and adequate walking space around piping and equipment.

During the initial permit period in 2023, TCEQ required a study to determine the corrosivity of the raw and treated rainwater. The corrosivity test conducted at the Campsite determined that the water was slightly corrosive. Consequently, TCEQ mandated the addition of a pH balancer to the raw rainwater and a corrosivity inhibitor to the treated water to ensure the system's longevity.

As of October 2024, TCEQ provided operating and testing clarification for the PWS system at the Campsite. These clarifications allow for increased efficiency and water conservation on-site. The Campsite is no longer required to operate and test the PWS plant daily to obtain the previously mandated daily readings. To meet TCEQ record keeping requirements, the plant had to be running in order to produce water and acquire water quality readings, even if water did not need to be produced that day. The previous requirement resulted in the waste of water and was time-constraining for the operator. Due to the ephemeral nature of the system with fluctuating demand based on users, operating the system 24/7 was inefficient, leading to unnecessary water and energy consumption, lowering the overall efficiency of the Campsite.

The Campsite is no longer required to operate the water production system daily during periods of no demand, nor is an operator required to be on-site daily when in a partial shutdown period, reducing the operation time by 30%. However, the distribution pumps for the filtered water must remain on, and the system must stay pressurized. This new operating procedure has increased overall water conservation at the Campsite by reducing unnecessary production of potable water, while also lowering the gallons used per day by eliminating the production of water for quality testing.

CONCLUSION

As Texas grapples with escalating water scarcity in the face of extreme regional population growth and climate change, the Campsite presents a model by reimagining water management through integrated One Water approaches. The Campsite at Shield Ranch is a pioneering example of on-site sustainable water and energy management in Texas, displaying One Water innovation, a commitment to stewardship, and conservation education. By becoming the first public water system in the state to rely entirely on RWH for potable supply, the Campsite has proven that decentralized, off-grid solutions are viable despite the onerous current regulatory frameworks. The RWH system at the Campsite is a practical example, building foundational knowledge and proving that RWH can be a reliable strategy in Texas.

The Campsite leadership's willingness to implement a new type of public water system now offers insights into the technical, regulatory, and operational hurdles. Lessons learned—from designing infrastructure to meeting changing and complex permitting processes—can inform future projects and guide policymakers in fostering an environment conducive to innovative, decentralized One Water solutions. Furthermore, the Campsite's emphasis on user and visitor education has further amplified its impact.

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