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Why Is Residential Irrigation So Hard to Optimize?

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Abstract: Irrigation of residential landscapes is one of the largest demands for municipal water suppliers. However, it is often done inefficiently and is a concern for limited capacity and low pressure. Why, really, is residential landscape irrigation so inefficient, and why is it so difficult to optimize? The problem, as we suggest framing it, comes down to four C's: conditions, components, controls, and customers. The conditions for efficient irrigation are too complex, sprinkler components are too imprecise, sprinkler controls too simplistic, and most water customers are too untrained as irrigators. Any management system with so many weaknesses is sure to be inefficient. Better plant choices, better landscape layouts, and precision irrigation technology are obvious solutions. Beyond these solutions, we recommend further development of smart irrigation controllers that account for the complexity of irrigation conditions and allow remote control by the water supplier. For an incentive, owners can opt-in and occasionally have their irrigation delayed or skipped if the water supplier needs to shed demand. We call this an "integrated water distribution system" where one benefit is a discretionary water demand that can be coordinated between suppliers and customers.

Keywords: irrigation; sustainability; efficiency; water; sprinkler; utility; smart controller; integrated water distribution system

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1. Introduction

The American West has been particularly hard hit by drought, as water levels in Great Salt Lake, Lake Powell, and Lake Mead tell [1,2]. Irrigation of residential landscapes, whether with potable water or alternative sources in parallel systems, is one of the largest demands for municipal water suppliers, regularly making up 30% to 50% of residential water use in many states, and sometimes even up to 90% [3,4].

However, residential irrigation is often inefficient and, as such, is naturally at the forefront of contemporary water management discussions. Shurtz et al. [5] found that half of residents in two Utah study areas were overwatering and that the excess water was harming rather than helping their landscapes. For a study area in Texas, Lewis et al. [6] determined that overwatering customers were a minority of the customer population yet were responsible for the largest percentage of overwatering by volume. The majority of these overwatering customers wasted approximately one month of indoor water use over a given irrigation season.

Besides the effect on total volume, residential irrigation is the cause of peak demands in many water distribution systems and is therefore a concern for limited capacity and low pressure. Beal et al. [7] determined that residential irrigation is also the driving force of peak hourly demands. Both points emphasize the need for greater optimization in residential irrigation, a widespread and timely sociotechnical problem.

With so much commentary—much of it conflicting—some of the fundamentals have been lost. Why, really, is residential landscape irrigation so inefficient? And why is it so difficult to optimize? We explore these issues through a new framing of the problems and suggest a solution to the often overlooked one involving real-time coordination of demand and supply between water customers and water utilities.

2. The Problem

The problem, as we have come to view it after reviewing the literature and considering our professional experience in the planning, design, and regulation of water systems, comes down to four C's: *conditions*, *components*, *controls*, and *customers* (Figure 1). Framing the problem in this manner breaks it down into pieces that suggest particular solutions.

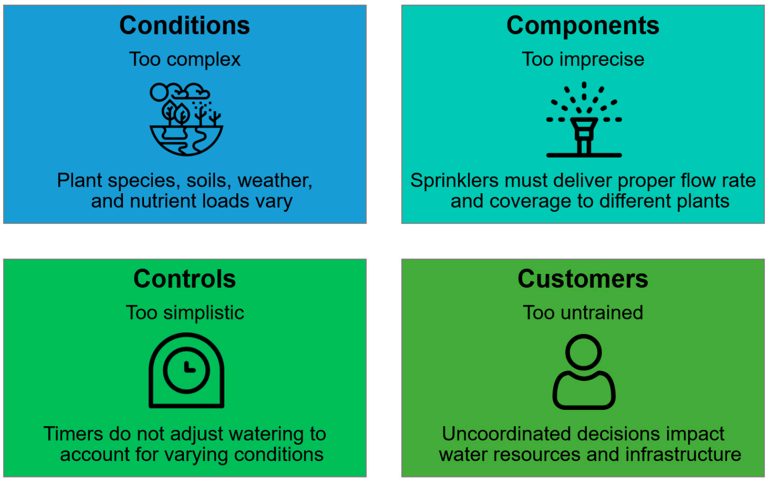

Figure 1. The four C's framework of irrigation inefficiency.

First, the *conditions* are too complex. Residential landscapes are part natural and part engineered. The natural (biological) part may include several plant types with different water needs [8], for example, turf, deciduous trees, decorative grasses, perennial shrubs, and annual flowers (Figure 2). Even for a given plant species, water demand depends on soil type (water storage), sun/shade, and slope, which vary with its placement in the yard. A plant's water demand also changes with its leaf area, the nutrient stock (partly a function of the owner's fertilizing practices), and atmospheric conditions; a cool, rainy day has very different evapotranspiration than a hot, windy day. Simply put, there are dozens of variables in play for conditions that change with plant, space, and time [9], and efficient irrigation must address all of these variables.

Figure 2. A residential landscape.

Second, the typical *components* of residential sprinkler systems are too imprecise. The physical layout of residential landscapes—the engineered part—often results in small, irregular, isolated areas such as park strips (between the road and the sidewalk) and flower beds (Figure 2) that are difficult to cover efficiently with standard sprinkler heads [5,9]. They lack the economy of scale of large open spaces. The problem compounds with the challenge of targeting different types of plants with specific flow rates or dividing a yard into appropriate zones. While drip equipment is available, many sprinkler systems may not be set up to accommodate the diverse watering needs of turf, trees, shrubs, and flowers. Further, the in-ground components of sprinkler systems are expensive to retrofit when landscapes are already constructed on top of them.

Third, sprinkler *controls* are too simplistic. With so many variables to consider, the magnitude, frequency, and duration of irrigation should be adjusted constantly to match the conditions. Mechanisms have evolved from manual watering to timers to smart controllers. Manual watering is the least sophisticated but the most labor intensive, often described as "hose dragging", and can lead to inconsistent landscape quality. Analog programmable timers offer convenience and automation, allowing users to set particular watering days, start times, and durations for each zone, but many users stick to a fixed watering schedule throughout the season and therefore tend to overwater. Smart controllers are the next iteration, combining the automation of timers with the ability to forecast weather, consider actual plant types, and communicate with the user, thereby satisfying both convenience and landscape quality. However, market penetration of smart controllers is still quite low and timer controls persist [3,10].

Finally, *customers*, as a group, are too untrained. Several studies document that many customers overwater landscapes due to the lack of adequate irrigation training, skills, and knowledge [3,5,11]. While a few are well informed, most know little of plant, soil, and water science, yet millions of them make daily decisions about how to use water resources. They have varied expectations of their landscapes [8] and do not realize how their landscaping practices and water use decisions impact the distribution system in terms of flow, pressure, and storage. In any industry, a management system with non-expert operators is sure to be inefficient. Water suppliers may deploy certain policy tools to their customers to overcome this challenge by providing training, encouraging water conservation, charging appropriate fees, and offering free sprinkler checks, but water suppliers otherwise have little control over how customers impose demands on their infrastructure and resources.

3. The Solution

With such intricate needs and inadequate tools, no wonder residential irrigation is so hard to optimize. We suggest a few solutions, some of which need further research. While they are largely technological, they should be supported by complementing policies.

But why bother improving residential irrigation at all? If it is so bad, why not cut it off altogether? Unchecked water use obviously cannot continue, but the opposite extreme, ceasing all residential irrigation, is just as unwise. Urban landscapes provide important services: recreation, shade, habitat, runoff attenuation, temperature regulation, dust control, and green spaces to beautify communities [12–14]. These factors are sometimes overlooked in the quest for efficiency. Instead, a compromise that allows landscapes to fulfill the same services but with less water is the most prudent.

To this end, much of the water conservation literature revolves around landscape transformation. Experts recommend removing non-functional (ornamental) turf and replacing it with native plants, xeriscaping, and other landscape choices that better fit the local environment and its water constraints. Such practices reduce overall consumptive water demand from landscapes and remediate all of the four C's. Studies of landscape transformations have observed water volume reductions, peak demand reductions, increased customer satisfaction, and long-term persistence of results [15].

Better landscape layouts can help too [16]. Besides the need to be functional, areas that are contiguous and homogenous in terms of sun, soil, and plant type will simplify some of the complex environmental conditions and trivialize the imprecision of sprinkler systems, thereby addressing two of the four C's. Good layouts are also easier to maintain with fewer edges, accessible shapes, and more consistent growth conditions.

Drip irrigation overcomes the limitation of imprecise components, at least for trees and shrubs laid out as a separate zone. Drip irrigation systems have tubes and emitters that deliver water directly to the soil near the plant roots, avoiding overspray onto surfaces that do not need water. For functional turf areas, various spray nozzles can accommodate particular angles, shapes, and distances. More components continue to be developed with smarter features. Drippers and sprinklers have different purposes, and both should be considered for good project design. Additionally, subsurface drip irrigation is an emerging technology for turf grass applications. This technology has long been used in the agricultural industry but is now being studied for residential irrigation purposes. Research is demonstrating an additional 30% water savings over sprinkler irrigation due to the low evaporation and no wind effect for the subsurface application [17].

Smart irrigation controllers are a major advancement because they remove most of the guesswork previously performed by customers. These sophisticated controllers take initial inputs on plant types and other site conditions (the first of the four C's) and suggest an optimum watering plan. They also connect to weather forecasts to adjust for changing conditions of temperature, precipitation, and wind. Hundreds of such models are now on the market, and recent reviews suggest that they can reduce water consumption by 15% to 40% [10,18]. Unlike constructing a new landscape or rebuilding an entire sprinkler system, upgrading to a smart irrigation controller is neither expensive nor disruptive, and many water suppliers offer rebates for such devices.

Even with ideal landscapes and advanced controllers, customers still drive water demand, and water suppliers can only react. This remains a fundamental flaw in efficiently delivering irrigation services. For the fourth and final piece, therefore, we envision a more transformative solution: the integrated water distribution system. We propose the idea as an extension of smart irrigation technology that remotely coordinates discretionary water demands such as landscape irrigation at customer endpoints according to capacity in the water supplier's delivery system. We elaborate on this concept in a review paper [18].

A water supplier could provide free or discounted remote-enabled smart irrigation controllers to homeowners who opt-in. If the supplier needs to shed water demand at a certain time when the capacity is limited, they could activate remote controls for selected endpoints to delay or skip irrigation. The homeowners could be notified of any delays or skips. Typical residential properties in Utah, for example, might need 1 or 2 h for an irrigation cycle every 3 days during summer conditions; even considering only the overnight periods offers considerable flexibility for adequate irrigation without compromising landscape quality because there is a large time window for a short irrigation cycle. An example of a water supplier providing free smart irrigation controllers is Spanish Fork, Utah. They have provided approximately 3500 professionally installed controllers, resulting in a 17% water savings with additional benefits of reducing peak day demands and delaying infrastructure upgrades, according to reports [19] and personal communications with city staff.

The integrated water distribution system concept coordinates supply and demand in a way that benefits both parties. When the supplier has greater control over demands, the level of service is more stable, avoiding the high peak flows and extreme pressure fluctuations that arise when customers choose when to irrigate. The usual benefits of smart irrigation controllers also come in, being able to match the complexity of environmental and site conditions to adjust the amount of watering for what the plants need. Customers benefit from the automation and the stabilized level of service.

Ultimately, solutions that optimize irrigation only on the customer's side, without interaction with the supplier's system, will fall short. An automated, real-time scheme to align residential customers' irrigation demand with water suppliers' capacity is a critical piece. We encourage it to be developed as a priority in urban water sustainability—for both users and suppliers.

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