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Review Article

Residential Irrigation Restrictions and Water Conservation: A Review of Studies from 1978 to 2022

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Abstract: Urban water managers and policymakers have adopted demand management strategies to reduce water use and buffer against short-term water supply shortfalls. This article provides a systematic review of publications from 1978-2022 that examine the effectiveness of residential water use restrictions as the primary demand-side management tool. Our results indicate the significant overall effect of restrictions on reducing water consumption, with an average reduction of 12.3% from the 23 studies reviewed in this article. When evaluating effect strength by restriction type (mandatory versus voluntary), voluntary restrictions have a significantly lower effect than mandatory restrictions on water use. We also find an inverse correlation between the number of irrigation days allowed and the estimated effect strength.

Keywords: *residential irrigation restrictions, conservation policies, watering days*

Droughts worldwide are intensifying, with increased frequency, duration, and severity (Diffenbaugh et al. 2015; Keremane et al. 2017; Chiang et al. 2021). Climate-induced droughts, combined with population growth, have escalated pressures on urban water systems. Countries like Australia, South Africa, and the state of California have all had to develop various solutions to combat water scarcity resulting from these persistent droughts. With supply-side management options becoming increasingly limited due to the scarcity of untapped reservoirs, particularly in areas prone to recurrent droughts (Molle et al. 2010; Berbel and Esteban 2019), the focus has shifted to demand-side strategies for water management.

Demand-side management strategies, which include measures such as water pricing, financial incentives, and regulatory approaches like water quotas and usage restrictions, have taken precedence in urban water management (Olmstead et al. 2007; Olmstead and Stavins 2009; Mansur and Olmstead 2012; Baerenklau et al. 2014; Buck et al. 2021; Lee et al. 2021; Lee et al. 2022). A notable strategy is outdoor watering restrictions as an emergency response, which can be voluntary or mandatory. Such policies limit the number of days per week for watering (e.g., two days). During the 2020-2022 drought, for instance, California's urban water suppliers imposed restrictions on outdoor watering days (Nemati and Lee 2022). Additionally, in June 2022, the Metropolitan Water District of Southern California (MWD) introduced an Emergency Water Conservation Program, mandating one-day-per-week watering restrictions for millions in Los Angeles, Ventura, and San Bernardino Counties (Metropolitan Water District of Southern California (MWD) 2022).

These restrictions are not unique to the American Southwest; they are a global phenomenon. For example, in eastern Florida, 81 municipalities within the St. Johns River Water Management District have enforced watering restrictions, alternating between two days a week during dry seasons and one day during wet seasons (St. Johns River Water Management District 2022). Since 2011, Australia has enforced permanent emergency water restrictions in the Australian Capital Territory and Victoria (Australian Government Bureau of Meteorology 2022; Melbourne Water 2022;

Research Implications

- Analysis of 23 studies shows outdoor watering restrictions lead to a significant water demand reduction, with a reported average effect strength of 12.3%.
- Combining restrictions with other water conservation strategies like informational campaigns, rebates, and audits enhances their effectiveness.
- The success of mandatory restrictions depends on robust implementation, enforcement, and support from additional conservation policies.

Victorian State Government Environment 2022).

The effectiveness of restricting watering days can vary, being either mandatory, voluntary, or a combination of both, and is contingent upon the drought's severity, local climate, and geographic factors. A mild drought necessitates a less stringent response than a severe, prolonged one. For instance, the 2011-2016 California drought, the state's worst in over a millennium, called for a comprehensive policy approach (Griffin and Anchukaitis 2014; Browne et al. 2021). In such extreme cases, reducing irrigation days to once or twice weekly was a critical measure to close the significant gap between water supply and demand (Scauzillo 2017).

Although widely implemented by water agencies and policymakers, the effectiveness of outdoor watering restrictions has yielded inconsistent findings. Some studies report negligible impacts on water use (e.g., Robinson and Conley 2017; Hayden and Tsvetanov 2019; Dronyk-Trosper and Stitzel 2020), while others suggest reductions of 21 to 33% (e.g., Kenney et al. 2008; Mini et al. 2014; Browne et al. 2021). Analyzing various watering day strategies could clarify which are most effective at decreasing water consumption.

Our systematic review encompasses 23 studies from 1978 to 2022, investigating the effect of these restrictions on residential water use. Our objectives include a systematic review of the average effect of irrigation restrictions on residential water consumption, an examination of the variance in reported effects considering variables like location and season, and an assessment of the combined impact of irrigation restrictions with other conservation policies, such as audits, informational campaigns, and rebates.

Methods

We performed a systematic literature review using search terms ("watering days," "urban irrigation restrictions," and "water demand management") in various databases for publications studying the effectiveness of outdoor watering day restrictions. To reduce the risk of missing relevant studies, we applied the same search terms to various relevant journals, such as the *Journal of Utilities Policy*, *Environmental Economics and Management*, and *The American Water Works Association*.

We began the search on January 1, 2022, finishing the process on July 30, 2022. We searched without imposing restrictions on date or year, location, study design, study aim, or inclusion/exclusion criteria. Using the search procedure, we retrieved 112 articles published between 1978 and 2022. From this pool, we examined titles and abstracts, eliminated studies that did not focus on the effectiveness of irrigation restrictions, and estimated the amount of water saved. There were many articles on residential water conservation that instead focused on other policies or policy outcomes, such as price-based conservation strategies or welfare impacts of irrigation restrictions (e.g., Brennan et al. 2007).

The 23 articles identified as meeting the search criteria span 44 years of data in 12 distinct regions worldwide. The information from these articles was manually entered into a database, with each estimate of water savings as one observation. In this study, each reported "effect strength" in percentage terms is an observation for the study, defined as the percentage change in water use under irrigation restrictions. Note that each study could report more than one effect strength. A negative (positive) effect strength indicates a reduction (increase) in consumption due to the irrigation restrictions in place. Other factors entered for each observation include things such as the type and extent of the restrictions examined, concurrent water conservation policies, and study design.

One factor that is considered for water conservation policies is seasonality. Many irrigation restriction policies permit a different number of irrigation days for summer months and winter months. The differences in temperature, precipitation, and plant growth across seasons impact the irrigation demands. Water utilities respond by altering the number of watering days allowed by season. For this reason, the irrigation restriction effect strength was divided into the seasons from which the data were collected. The season variable was divided into three categories: "Summer," "Winter," and "Summer + Winter." Summer generally refers to April through September, and Winter refers to October through March. Summer + Winter refer to data collected across both time periods, most often over the entire year. The exact cutoff between summer and winter months is not uniform; the time frames given here broadly represent those used in the sample. Differences in seasonal effect strengths could be attributed to a strong association between seasonal changes in residential water demand and irrigation behavior (Kjelgren et al. 2000). Due to the higher temperatures and lower precipitation, people water their lawn more in the summer than the winter, meaning summer has a greater potential in reduction in the amount of water used in irrigation than winter.

Results

Summary of Peer-reviewed Articles Search Results

In Table 1, we provide a list of all 23 articles, study location, information on the irrigation restriction, and findings. This was the dataset used to examine the effectiveness of residential irrigation restrictions under varying circumstances, including time periods, locations, political situations, and conservation strategy bundles. The diverse circumstances in the dataset provide a unique look into which of these additional variables could lead to more successful implementation and effectiveness of residential irrigation restrictions.

The area with the greatest number of published studies was the Southwestern United States. California and Colorado were the subjects of six publications each, comprising more than half of the sample. Other regions with arid or semi-arid climates, such as Texas, Oklahoma, and New South Wales, were also represented in the dataset. Despite having climates and geographical features dissimilar to the other included regions, Florida, Massachusetts, Pennsylvania, and North Carolina were the subject of multiple publications, all within the last 16 years. Some publications chose to focus on mandatory restrictions without a limit on watering days (e.g., Grafton and Ward 2008). Some examined more stringent mandatory restrictions (e.g., Kenney et al. 2004; Browne et al. 2021). Others have examined both (e.g., Haque et al. 2013).

As indicated in Table 1, the overall estimated strengths range from the order of 1.6 to 34% reduction in water use (Maggioni 2015; Renwick and Green 2000). Some assessments of irrigation restrictions found them ineffective (e.g., Robinson and Conley 2017; Dronyk-Trosper and Stitzel 2020), while some found them to be significant tools for demand reduction (Anderson et al. 1980; Kenney et al. 2008).

Data from the 23 studies produced 251 total reported effects, summarized in Table 2. The average reported effect strength from the dataset was -0.123, meaning that, on average, irrigation restrictions lead to a -12.3% reduction in water consumption. When evaluating effect strength by restriction type (i.e., mandatory, voluntary, and mandatory plus voluntary), voluntary restrictions had a much lower effect than mandatory or mandatory plus voluntary restrictions. The high and low bounds for voluntary restrictions were estimated between no effect and roughly a 10% reduction.

Effect Strength by the Number of Irrigation Days Allowed

Figures 1 and 2 show the distribution of reported changes in water use across the number of irrigation days allowed. Figure 1 is on a per-study basis, taking the average estimated effect strength and number of irrigation days allowed in the study into a single point. This produced 23 points, one for each publication. The average estimated effect strength decreases as the number of permissible days increases, and vice versa. The maximum

Table 1. Summary of peer-reviewed literature on irrigation restrictions' effectiveness, with numbers in brackets indicating reported lowest and highest effect strength within each study.

Citation	State/Region	Watering Days Allowed	Additional Non-Price Strategies?	Overall Estimated Effect strength
Anderson et al. 1980	Colorado, U.S.	2	No	-0.304 [-0.197, -0.41]
Asci and Borisova 2014	Florida, U.S.	1-2	Yes	-0.173 [0.054, -0.556]
Browne et al. 2021	California, U.S.	1-2	Yes	-0.233 [-0.112, -0.338]
Dronyk-Trosper and Stitzel 2020	Oklahoma, U.S.	2-3	No	-0.018 [-0.007, -0.038]
Grafton and Ward 2008	New South Wales	7	No	-0.114 [-0.084, -0.144]
Halich and Stephenson 2006	Virginia, U.S.	-	Yes	-0.149 [-0.068, -0.154]
Haque et al. 2013	New South Wales	3-7	No	-0.158 [-0.0913, -0.201]
Haque et al. 2014	New South Wales	2-7	Yes	-0.113 [-0.039, -0.201]
Hayden and Tsvetanov 2019	California, U.S.	4	No	-0.00957 [-0.00635, -0.0256]
Kenney et al. 2004	Colorado, U.S.	1-2	Yes	-0.233 [0, -0.56]
Kenney et al. 2008	Colorado, U.S.	2	Yes	-0.334 [-0.031, -0.85]
Krohn 2019	Pennsylvania, U.S.	-	Yes	-0.0291 [-0.0037, -0.0498]
Maggioni 2015	Colorado, U.S.	-	Yes	-0.016 [-0.015, -0.017]
Miller 1978	Colorado, U.S.	2	Yes	-0.212 [-0.212, -0.212]
Mini et al. 2014	California, U.S.	2-7	Yes	-0.205 [-0.06, -0.35]
Renwick and Archibald 2018	California, U.S.	-	Yes	-0.155 [-0.151, -0.159]
Renwick and Green 2000	California, U.S.	-	Yes	-0.34 [-0.34, -0.34]
Robinson and Conley 2017	Massachusetts, U.S.	-	No	-0.018 [0.0263, -0.0385]
Shaw and Maidment 1987	Texas, U.S.	1-2	No	-0.0314 [0.0025, -0.0791]
Soliman 2022	California, U.S.	3	No	-0.195 [-0.153, -0.261]
Stone 2011	Colorado, U.S.	2	Yes	-0.063 [-0.0436, -0.0927]
Whitcomb 2008	Florida, U.S.	2	No	-0.0831 [0, -0.169]
Wichman et al. 2016	North Carolina, U.S.	2-3	No	-0.0897 [-0.029, -0.153]

Table 2. The summary statistics from the 23 publications included in this study.

	Mandatory	Voluntary	Mandatory & Voluntary	Overall
Total number of observations	179	51	19	251
Average reported effect strength*	-0.144	-0.049	-0.129	-0.123
Minimum reported effect strength	0.054	0.00	0.026	0.00
Maximum reported effect strength	-0.56	-0.097	-0.85	-0.85

*Negative effect strengths represent a reduction in water use, and positive effect strengths represent an increase in water use. For example, -0.123 means, on average, watering days restrictions lead to a 12.3% reduction in water use.

number of days allowed for irrigation is seven, which is equivalent to a voluntary restriction. Each successive decrease in the number of irrigation days allowed reduces the water used.

In Figure 2, each point is a reported effect strength (i.e., multiple reported effect strength per study), giving a single point to every reported effect strength in the database with a corresponding number of irrigation days allowed. Figure 2 displays similar trends to Figure 1. This is best seen by comparing the two extremes of the x-axis. Allowing irrigation seven days of the week yields little to no change in water use. In comparison, one to two watering days a week has been shown to provide a much more consistent and significant estimated reduction in demand.

An evident cluster of data points between one and three irrigation days is allowed in both figures. Irrigation restrictions are often implemented to reduce the number of allowed days to the minimum amount required to sustain grass. This is done to prevent users from overwatering their lawns by exceeding the recommended one to two days per week of watering in standard conditions.

Effect Strength by Season and Irrigation Restriction Type

Across all seasons and restriction types, the average estimated effect strength is -0.123, a 12.3% reduction in demand across the full sample. When grouped by restriction types, the difference between mandatory and voluntary irrigation restriction estimated reduction rate was clear. Mandatory restrictions, with an overall estimated effect strength equal to a 14.4% reduction, are nearly ten percentage points greater than voluntary restrictions at 4.96% (Table 3). While an estimated 5% reduction from voluntary restrictions is noteworthy, the upper limits of voluntary and mandatory restrictions illuminate the disparity between their ability to create significant demand reduction.

As illustrated in Table 3, when examining estimated effect strengths by season, overall, “Summer” had an estimated effect strength equal to a 15.3% reduction, compared to a 11.6% reduction for “Summer + Winter.” While “Winter” had a larger rate of reduction with -0.193, a sample size of three has limitations. When examining the average estimated effect strengths for mandatory restrictions, a similar relationship was apparent; mandatory restrictions have a reduction rate of 20.6% in the summer and 13.2% across both seasons. This trend does not hold when comparing seasonality under voluntary or mandatory and voluntary. However, a trend that continues was the greater average estimated effect strengths for mandatory restrictions compared to voluntary restrictions for both “Summer” and “Summer + Winter.” Further interpretation of seasonal effect strengths is difficult. Residential water use in the winter is primarily indoors, compared to summer, where a greater proportion of use is outdoors; this has led scholars to note the difficulty in drawing conclusions based on seasonal changes, coupled with potential changes in policy, conservation behaviors and attitudes, among other confounding factors (Browne et al. 2021).

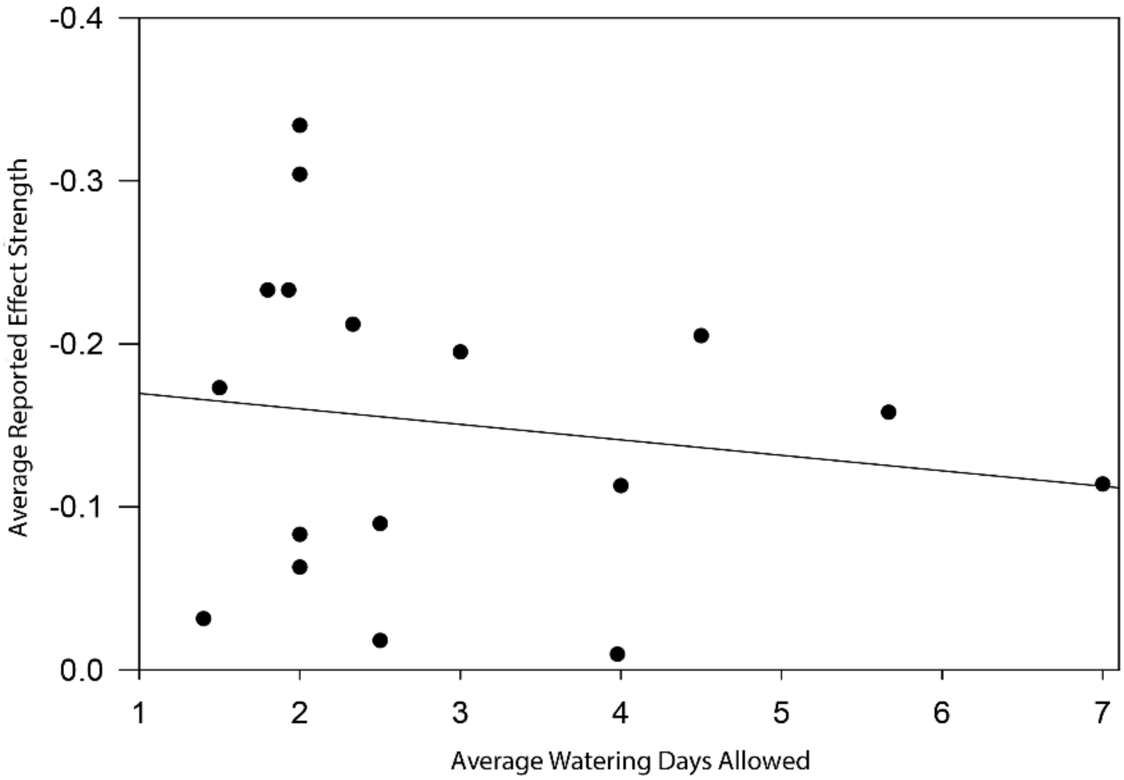

Figure 1. Reported effect strength (per study) by irrigation days allowed. The back solid line is the trend line.

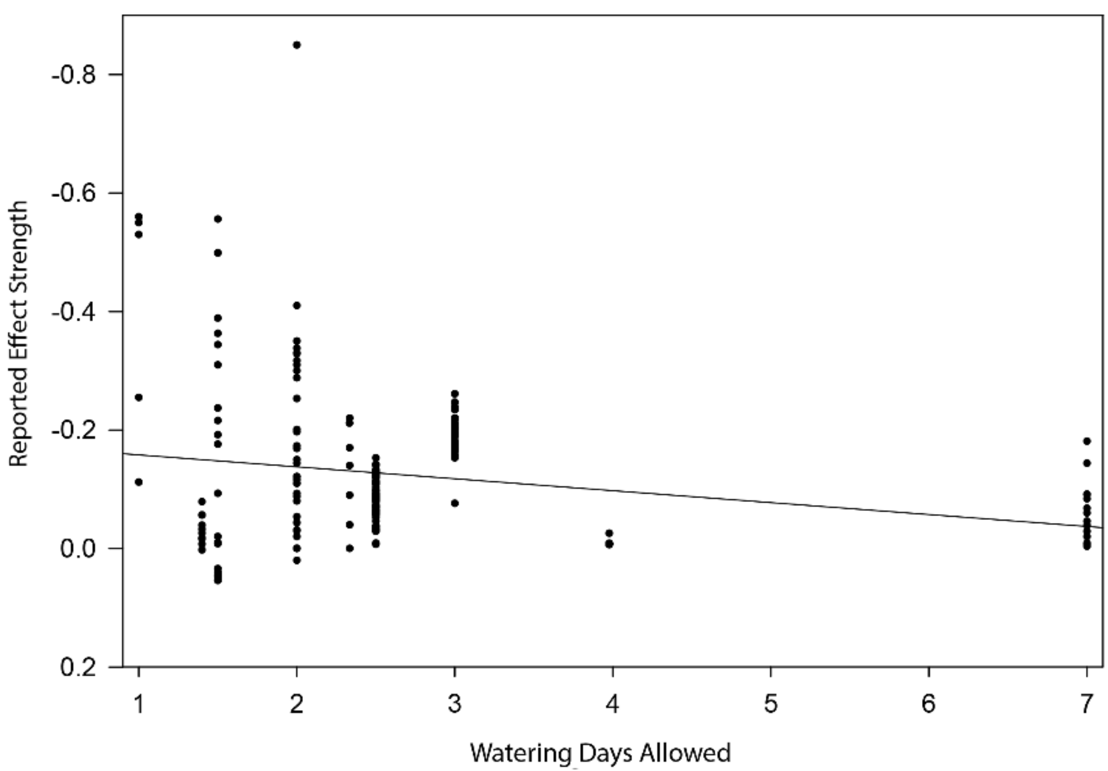

Figure 2. Reported effect strength by irrigation days allowed. This figure includes all the reported strengths in the study.

Table 3. The average reported effect strength (ARES) and number of observations (Obs.) by irrigation restriction type and season. Numbers in brackets report the reported effect strength range.

	Overall		Mandatory		Voluntary		Mandatory & Voluntary	
	ARES	*Obs.*	*ARES*	*Obs.*	*ARES*	*Obs.*	*ARES*	*Obs.*
Summer	-0.153 [0.026, - 0.56]	42	-0.206 [0.002, -0.56]	27	-0.0343 [0, -0.09]	10	-0.108 [-.038, -0.221]	5
Winter	-0.193 [-0.112, -0.256]	3	-0.193 [-0.12, -0.255]	3	-	-	-	-
Summer + Winter	-0.116 [0.054, -0.85]	206	-0.132 [0.054, -0.556]	150	-0.0522 [-0.004, -0.096]	41	-0.133 [-.007, -0.85]	15
Overall	-0.123	251	-0.144	180	-0.0496	51	-0.126	20

Effect Strength and Additional Conservation Policies

The impacts of the presence of additional conservation policies are presented in Table 4. The policies analyzed included three non-price policies: audit consultations, informational campaigns, and rebates. An audit consultation generally entails a government water consultant coming to a home to find water inefficiencies in the home and fix or suggest solutions to the issues found. Informational campaigns are wide-ranging education initiatives to teach better water use habits and new irrigation restriction regulations. Rebates are credits for discounts on water-efficient appliances such as low-flow toilets and shower heads. Price modifications account for a combination of two policies: price level changes and price structure changes. Audit consultations, informational campaigns, and rebates all correlate with a reduction in demand when used in conjunction with irrigation restrictions. The additional reduction effectiveness is to the order of 4.4, 6.3, and 5.6%, respectively. This contrasts with price modifications, where there is a negligible difference of 0.2%.

As noted in the methods and data section, these results could be misleading. For a strategy such as an informational campaign, they were not always mentioned by the studies and were thus marked as not being present when not mentioned. However, it is unlikely that an informational campaign was absent for more than a small selection of the sample, if at all. This applies in varying degrees to all the strategies recorded in the dataset. This creates non-representative figures with a disproportionately small number of observations.

Discussion

Based on the studies examined, mandatory residential irrigation restrictions are effective in reducing water demand. The degree of effectiveness varies between studies. Voluntary residential irrigation restrictions are ineffective; data on their effectiveness attribute little to no demand reduction across all studies examining it. Voluntary restrictions are unlikely to induce a meaningful reduction in usage or frequency without incentives to change outdoor irrigation habits. Mandatory restrictions often institute consequences for failed compliance, such as fines, rate increases, or even shutting off the water entirely. These enforcement standards likely induce the change that voluntary restrictions are not able to. This is shown in their average estimated effect strengths. Mandatory restrictions have an average 14.4% reduction in demand compared to an average 4.87% reduction for voluntary restrictions. Mandatory restrictions consistently outperform voluntary restrictions across seasons, locations, time periods, and concurrent policies.

Table 4. Average reported effect strength (ARES), number of observations (Obs.), and number of studies (# of Studies) by presence of additional conservation policies. Numbers in brackets report the reported effect strength range.

	With Conservation Policy			**Without Conservation Policy**		
Conservation Policies	*ARES*	*Obs.*	*# of Studies*	*ARES*	*Obs.*	*# of Studies*
Audit Consultation	-0.163 [0.054, -0.556]	23	3	-0.119 [0.0263, -0.85]	226	20
Informational Campaign	-0.173 [0, -0.85]	54	10	-0.109 [0.054, -0.56]	197	13
Rebate	-0.175 [-0.015, -0.85]	17	7	-0.119 [0.054, -0.56]	234	16
Price Modification	-0.122 [0.054, -0.85]	187	17	-0.124 [0.0263, -0.41]	64	7

Mandatory restrictions can be more likely to succeed through their implementation, enforcement, and additional conservation policies. It is not possible to force compliance without proper infrastructure and enforcement mechanisms. Similarly, without an effective strategy for implementation, the restrictions are unlikely to succeed. Examples of poor implementation include poor information dissemination, too few or too many irrigation days, or a lack of complimentary conservation policies. Avoiding these mistakes can produce better policy outcomes.

As the number of irrigation days allowed decreases, the amount of water conserved increases. The optimal number of irrigation days allowed is difficult to determine, however. It stands to reason that allowing six days of irrigation per week would not significantly change water demand. On the other hand, allowing a single day of irrigation would significantly reduce demand. According to the studies analyzed, the most common number of irrigation days allowed is around two. However, the effectiveness of two irrigation days per week is more mixed. The average effect strength of a two-day-per-week policy is a 16.13% reduction. The most optimistic study estimates a 33.4% demand reduction compared to the least optimistic estimate of a 1.8% demand reduction. The optimal number of irrigation days was not determined in this study. A higher order of demand reduction is induced by allowing fewer irrigation days. This trend, coupled with the ubiquity of two-day-per-week policies, suggests that they are likely optimal. A potential study on the optimal number of watering days could have a large impact on future policy decisions and can hopefully be completed in the future.

According to the studies analyzed for this review, mandatory restrictions reduce demand by 14.4% on average. Thirteen out of 23 of the studies analyzed include additional non-price policies, though this is almost certainly an underestimation. Given that the estimates of reduction from this review are based primarily on irrigation restrictions with policy bundles, the use of irrigation restrictions as the sole policy in many California agencies is unlikely to induce the change necessary to meet their conservation goals.

The research included in this review mirrors the sentiments of economists on price-based policies. While the consensus had been that price policies reduced demand in the short run, more recent analysis has argued that water is an inelastic commodity in the short run, making price-based policies ineffective in reducing consumption (Haque et al. 2013). Some have concluded that price-changing policy mainly falls on the poor while not creating significantly different policy outcomes between income groups (Wichman et al. 2016). The results indicated in Table 4, while not fully in line with the conclusions of economic and policy researchers, do point toward the ineffectiveness of price-based policies. Table 4 does, however, show the significant demand reduction created by non-price policies.

The increasing frequency and severity of droughts worldwide, and the subsequent need to reduce water consumption, will require more robust policies to further reduce demand. Water utility agencies should therefore seek to implement a diverse set of price and non-price strategies to optimally reduce demand. Not every agency has the means to employ all the conservation strategies discussed in this review. What works for one agency will not necessarily work for another. Irrigation restrictions are a valuable tool in reducing residential water use. Other price and non-price policies should be considered and implemented when instituting mandatory irrigation restrictions. Irrigation restrictions have a ceiling for reducing demand. When coupled with other compatible policies, further demand reduction is possible.

A common obstacle to policy implementation is political backlash. Water conservation policies require a change in lifestyle for the people living under them. This will inherently make them unpopular with a significant percentage of the municipality. While a more extreme policy package may be the most effective choice, the political repercussions may require decision-makers to implement a more conservative package.

Conclusion

Mandatory residential irrigation restrictions are growing in usage across the world in line with the increased frequency and severity of droughts. This review investigated the effectiveness of irrigation restrictions across various policies, locations, climates, and time periods through the analysis of 23 academic sources examining the effectiveness of irrigation restrictions. Using the data from these sources, we found evidence that such restrictions are likely to reduce residential water demand.

The effectiveness of mandatory irrigation restrictions was found to increase when the number of irrigation days allowed was decreased. Similarly, effectiveness was found to be higher with the implementation of additional non-price conservation measures such as rebates, informational campaigns, and audit consultations. The presence of price conservation measures is linked with negligible changes in demand. These results indicate that mandatory residential irrigation restrictions are effective in reducing demand and are more effective than voluntary restrictions. Additional policies are likely to increase the total reduction in water demand. A definitive best policy package is not provided, given the differing circumstances of each utility agency. However, introducing multiple conservation methods may produce better conservation outcomes.

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