EVALUATION OF IRRIGATION RESTRICTIONS IN EAST-CENTRAL FLORIDA

Prepared for and funded by:

St. Johns River Water Management District
4049 Reid Street
P.O. Box 1429
Palatka, FL 32178-1429

Prepared by:

John B. Whitcomb, PhD
(800) 800-9519

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EXECUTIVE SUMMARY

Irrigation restriction is one of the tools available to water managers to reduce water use during times of water shortage. Restrictions typically are applied during periods of drought, when the compounding circumstance of decreasing water supplies and increasing irrigation-water demands exist. Restrictions also can be applied during non-shortages to encourage efficient irrigation practices.

The St. Johns River Water Management District (District) issued a water-shortage order, effective January 15, 2001, for its East-Central region, which covers portions of Marion, Lake, Orange, and Brevard Counties and all of Seminole and Volusia Counties. The water-shortage order applied to every water user, regardless of supply source, not otherwise regulated by a District-issued Consumptive Use Permit. The order included residential, commercial, and industrial properties. Golf courses, agriculture, and nurseries had unique provisions to reduce water use. The irrigation restrictions remained in effect until March 1, 2006, when the District amended and geographically expanded restrictions to cover all District water users.

The irrigation restrictions put into effect in 2001 included three key constraints:

- Landscape irrigation is restricted to a maximum of two days per week. Properties with odd-number addresses are allowed to irrigate on Wednesday and Saturday. Properties with even-number addresses are allowed to irrigate on Thursday and Sunday.
- Landscape irrigation is prohibited between 10 a.m. and 4 p.m.
- Irrigation shall only occur when actually needed because of lack of rainfall and shall be limited to the application of no more than ¾-inch of water in the irrigated area.

The objective of this study was to quantify the water savings associated with District irrigation restrictions in the period 2001–2004. Understanding the efficacy of irrigation restrictions can assist District and water managers in policy decisions related to the future use of irrigation restrictions in managing scarce water supplies. The District is using irrigation restrictions as a relatively long-term mechanism to promote efficient landscape irrigation, not just as a tool to cope through a short-term water shortage. Landscape experts agree that getting customers to irrigate less frequently can improve both water efficiency and the health of landscapes, especially lawns.

The history of reducing water use via irrigation restrictions in the United States is mixed. In some cases, irrigation restrictions can cause water-use reductions of over 50%. In other cases, irrigation restrictions actually might increase total water usage—some customers irrigate on allowed days, even if weather conditions do not warrant it, or they over-irrigate, as they know they will be restricted on future days. Hence, the efficacy of irrigation restrictions depends on local circumstances; there is no universal rule of thumb. Below, however, is a list of observations gleaned from reviewing the literature:

- Enforcement
  Water savings increase with enforcement of the restrictions. Voluntary irrigation restrictions prove less effective than mandatory restrictions. Enforcements through written warnings, financial penalties, and termination of water service improve restriction compliance. Effective communication and education can improve compliance and make enforcement easier.

- Restriction Severity
  Water savings increase with more severe irrigation restrictions. Going from three to two to one day-per-week irrigation, or once in 10 days, leads to greater water savings. The utilities reviewed universally used limiting irrigation to the morning and evening hours, when evapotranspiration is lower.

- Magnitude of Irrigation
  Water savings are higher for water utilities that have a relatively high portion of their total potable water use associated with irrigation. Utilities with large commercial and industrial customer bases are less impacted. Utilities with customers that irrigate from alternative sources, such as reclaimed wastewater, shallow irrigation wells, or surface water, experience less impact on their potable water use.

- Good Will
  Water savings from irrigation restrictions are higher for customers who understand and perceive the need of restrictions to assist their water suppliers through times of water shortages.

- Water System Peaking
  Water managers must carefully anticipate and adjust restrictions to limit water-use peaks exacerbated by day-of-week and time-of-day irrigation restrictions. Forcing all irrigation to occur in limited windows of time can stress the water system, leading to loss in water pressure and compromising fire-suppression abilities.

- Evaluation of Water Savings
  All studies that evaluated the water savings associated with irrigation restrictions controlled for weather. Ignoring weather can severely bias the results. When relevant, researchers also must control for customer growth and for the increasing use of alternative water-supply sources, in isolating the impact from restrictions.

This study conducted an empirical analysis of water-use data over the period 1997–2004 for the following eight utilities, subject to District irrigation restrictions:

- City of Apopka
- City of DeLand
- City of Ocoee
- City of Port Orange

- City of Sanford
- City of Winter Park
- Orange County Utilities
- Seminole County Utilities

Monthly water-use data were provided only for Ocoee and Seminole County Utilities. Daily water-production data were available for all but Seminole County Utilities.

This study's objective was to evaluate the times-series of water use to quantify the water savings from the restrictions. To accomplish this task, the evaluation used statistical methods to control for weather, seasonal water-use patterns, customer growth, and other factors that affect water use.

Results show that water savings from irrigation restrictions vary significantly with utility circumstances. The irrigation-restriction water savings associated with Ocoee and Seminole County are convincing. Both of these utilities have relatively high levels of outdoor water use.

Based on analysis of 6,332 single-family homes in Ocoee, the average decline in water use from 2001 to 2003 was 11.6–12.8%, after implementation of irrigation restrictions. The savings were weather-normalized and include only those homes that existed before 1998 and had a continuous water-use history from 1998 through 2003. The savings do not appear to have declined over time but are persistent. Water rates and other factors were constant over the study period, leading us to conclude that the water reductions were caused by the water restrictions.

The Ocoee results generated by analysis of billing data were supported by analysis of daily water-production data. After irrigation restrictions were implemented, water use significantly decreased on Mondays, Tuesdays, and Fridays—days when irrigation was prohibited. Water use, in contrast, increased on Wednesdays, Thursdays, Saturdays, and Sundays—days when irrigation was allowed. Hence, it is clear that irrigation restrictions drove the water-use reductions, as measured with the billing data. Ocoee is the only utility where we analyzed both billing and water-production data.

In Seminole County, we analyzed the water use of irrigation meters associated with 2,715 homes. The same owners occupied the homes over the entire study period from 1998 to 2003. The weather-adjusted water savings from 2001 to 2003 averaged 16.9–18.5%. These savings were based on water used only for irrigation, not total water use (including indoor uses). When put in a total home water-use perspective, the savings were similar to those calculated for Ocoee. The water savings did not diminish over time, leading us to conclude that water savings are persistent over time. Water rates and other factors were constant over the study period, leading us to conclude that the water reductions were caused by the water restrictions.

Our analysis of daily water production at six other utilities generated mixed and perhaps misleading results, if water-use changes are exclusively ascribed to irrigation restrictions. These utilities experienced large increases in population, ranging from 8% to 36% over the study period. Although adjustments for growth were made—dividing total water production by total estimated population—to put water use on a per capita basis, difficulties still exist. The relative proportions of commercial and residential customers, for example, were not always constant over time. An examination of Apopka, for example, shows that commercial customers grew much faster than residential customers over our study period. This can bias observations of per capita water use over time. In addition, new customers may have different water-use consumption than old customers—differences in water-fixture efficiency (e.g., toilets and showerheads) and landscape areas, plant materials, and irrigation systems challenge the assumption that per capita water use of new customers is the same as old customers. Further, all of the utilities studied are expanding wastewater reclamation to serve as a source substitute for potable water supplies. This also complicates the situation, as water-production data of potable supplies are impacted by such substitution. All of these phenomena tend to warp daily per capita observations over time in unpredictable ways. Hence, it is our conclusion that we cannot generally rely on daily water-production records to accurately estimate the annual water-use change associated with irrigation restrictions.

Daily water-production records, however, can be valuable in detecting and quantifying changes in the day-of-week water-use pattern. If irrigation restrictions are effective, then we will see a drop in water use during non-irrigation days and an increase on designated irrigation days. Detecting relative day-of-week changes is not materially impacted by customer growth, reclaimed wastewater, or other complicating factors.

Our analysis shows that the day-of-week patterns changed in concert with the irrigation restrictions at Orange County Utilities and Winter Park. Water use showed a strong relative increase on Sunday, Wednesday, Thursday, and Saturday—the days when irrigation was allowed. Water use dropped sharply on Monday, Tuesday, and Friday, when irrigation was prohibited.

The results for the other utilities are less clear. For Apopka, the odd-number street addresses showed the expected Wednesday and Saturday water-use increases. For the even-number street addresses, water use did not relatively increase. We are unsure of the cause. DeLand experienced its largest relative drop in water use on Monday and Tuesday, as expected, but not on Friday. Water use relatively increased on Saturday and Sunday. Water use on Wednesday and Thursday was less than we expected. Sanford and Port Orange have relatively little potable water use associated with irrigation, and hence, their day-of-week cycles were not significantly impacted by the restrictions.

As demonstrated with Ocoee, it is beneficial to look at both billing and water-production data when assessing the effectiveness of irrigation restrictions. Because Orange County Utilities has recently changed its billing database software, we were not able to collect historical billing data from them for this study. This is unfortunate, as Orange County Utilities showed a pronounced change in its day-of-week cycle of water production, indicating that restrictions changed customers' behavior. Because conditions disfavor the analysis of daily water production (e.g., high customer-growth rate) to quantify annual water savings, we are uncertain of the net impact of irrigation restrictions on customers. Future studies should aim to collect both billing and water-production data for the same utilities in follow-up assessments. Both sources of data provide a different angle, adding to our understanding of irrigation-restriction impacts.

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St. Johns River Water Management District Staff

Ima Bujak, Project Manager
Darryl Williams
Lisa Parks
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Participating Water Utilities

City of Apopka, Edward Bass
City of DeLand, Keith Riger
City of Ocoee, David A. Wheeler
City of Port Orange, John A. Shelley
City of Sanford, Paul Moore
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Orange County Utilities, Jacqueline Torbert
Seminole County Utilities, Bob Briggs

1. PROJECT DESIGN

This chapter contains four sections that describe the irrigation restrictions, project objective, empirical approach, and participating water utilities.

1.1 District Irrigation Restrictions

The St. Johns River Water Management District issued a water-shortage order, effective January 15, 2001, for its East-Central region, which covers portions of Marion, Lake, Orange, and Brevard Counties and all of Seminole and Volusia Counties. Appendix A contains documents that describe the order. The 2001 water-shortage order applied to every water user, regardless of supply source, not otherwise regulated by a District-issued Consumptive Use Permit. It included residential, commercial, and industrial properties. Golf courses, agriculture, and nurseries have unique provisions to reduce water use. The irrigation restrictions remained in effect until March 1, 2006, when the District amended and geographically expanded restrictions to cover all District water users.

The irrigation restrictions put into effect in 2001 included three key constraints:

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- Irrigation shall only occur when actually needed because of lack of rainfall and shall be limited to the application of no more than ¾-inch of water in the irrigated area.

The shortage order also included the following additional provisions:

- Personal vehicle washing must be done using a hand-held hose equipped with an automatic shut-off nozzle.
- Outside aesthetic use of water that uses non-recirculating fountains is prohibited.
- New landscape may be irrigated on any day between the hours of 4 p.m. and 10 a.m. during the first 60 days following installation. Whenever possible, the installation of new landscape should be postponed until this water shortage order is rescinded.
- Use of reclaimed water is allowed any time, but all users are requested to conserve and irrigate only when needed.

1.2 Project Objective

The objective of this study was to quantify the water savings associated with the District irrigation restrictions in the period 2001-2004. Understanding the efficacy of irrigation restrictions can assist the District and water managers in policy decisions related to the future use of irrigation restrictions in managing scarce water supplies. The District is using irrigation restrictions as a relatively long-term mechanism to promote efficient landscape irrigation, not just as a tool to cope through a short-term water shortage. Florida landscape experts agree that getting customers to irrigate less frequently can improve both water efficiency and the health of landscapes, especially lawns (Trenhom et al., 2002).

1.3 Empirical Approach

Historical water-use data were analyzed to quantify the water savings that resulted from irrigation restrictions. Conceptually, we wanted to compare water use ***before and after*** the implementation of restrictions, holding all other factors constant. This would allow us to isolate and measure the impact from the restrictions.

Unfortunately, all factors are not constant over time. Population growth within the District has been significant in most areas and the increasing use of reclaimed water as a substitute for potable water for irrigation is a complication. Weather changes also must be controlled for in the analysis.

These complications make it clear that our approach must be framed from a ***with-and-without*** perspective. We must compare water use with the restrictions to water use that would have been, if the restrictions had never occurred. This is more complicated than a simple before-and-after comparison, but it is necessary, given the circumstances. Our with-and-without approach relies on developing mathematical models of water use to guide the prediction of water use that would have been, if the restrictions had never occurred.

We applied our approach to two types of water-use data. We collected and analyzed both daily water production and monthly water use, related to meter readings made for billing purposes. Analyzing the advantages and disadvantages of each type of data added to our knowledge.

The advantage with analyzing daily water production is that we can detect day-of-week shifts in water use. The District irrigation restrictions allow water use on specific days (Wednesday and Saturday, Thursday and Sunday) and disallow it on others (Monday, Tuesday, and Friday). If the restrictions have an impact, these day-of-week shifts will be evident and can be quantified by analyzing the water-production data. The disadvantage with analyzing water-production data, however, relates to difficulties in controlling for other influencing factors that change over time, such as population growth.

The advantage of analyzing monthly billing data is that we can focus on specific properties during pre-restriction and restriction periods. This avoids the population-growth complication, as we focus on a static set of users over time. We still need to control for factors such as weather, but this is not relatively difficult. The disadvantage of analyzing monthly billing data is that water meters are read on a revolving monthly basis, which does not allow for observations about day-of-week changes.

Hence, the most efficient course combines data from monthly billing records with the best daily water production data that can be obtained.

1.4 Participating Water Utilities

We need to analyze the water use of multiple water utilities to gauge the range of efficacy of the irrigation restrictions under different circumstances. We expect differences in water savings, depending on variations in the following:

- Communication of irrigation restrictions to water users
- Enforcement of penalties associated with non-compliance with irrigation restrictions
- Magnitude of outdoor irrigation supplied by potable water utility sources
- Good will of people to follow the restrictions to help the community

Each water utility has a different mix of outcomes associated with these four parameters.

Data collection limitations, however, dictated that this study could investigate only a limited number of water utilities. District staff provided water-use data over the period 1997–2004 for the following eight utilities subject to the irrigation restrictions:

- City of Apopka
- City of DeLand
- City of Ocoee
- City of Port Orange
- City of Sanford
- City of Winter Park
- Orange County Utilities (OCU)
- Seminole County Utilities (Seminole)

Monthly water-use data were provided only for Ocoee and Seminole. Daily water-production data were available for all but Seminole.

2. DATA COLLECTION

For each of the eight water utilities that participated in this study, we collected a variety of information, including daily water production, monthly water-use billing records for single family homes, population, weather, irrigation restriction implementation details, and water and sewer prices. This data collection process and its results are described in this chapter.

2.1 Water-Use Records

District staff collected daily water-production data over the period 1997–2004 for seven of the utilities: Apopka, Deland, Ocoee, Port Orange, Sanford, OCU, and Winter Park. The aim was to collect four years of pre-restriction and four years of restriction data. If a utility has multiple water-treatment plants, we totaled all water use that resulted in water production for the whole utility service area. Water-production data included all utility water uses; water use for specific customer classes could not be distinguished.

Monthly water-use records for single-family homes from Ocoee and Seminole County Utilities were collected. Water-use data spanned 1998–2003.

2.2 Population

The District contracted GIS Associates, Inc., to provide annual estimates of population for each utility, as shown in Table 2-1. We divided daily water production by the annual estimate of population to arrive at gallons per capita day over the study period for each utility.

Table 2-1. Population by Utility and Year

Year	Public Supply Service Area Population Estimates & Projections						
	Apopka	**DeLand**	**Ocoee**	**OCU**	**Port Orange**	**Sanford**	**Winter Park**
1997	30,285	47,387	23,459	216,468	54,463	37,341	65,479
1998	31,122	48,237	24,568	225,593	55,766	37,710	65,784
1999	31,960	49,088	25,678	234,718	57,070	38,078	66,090
2000	32,797	49,938	26,787	243,842	58,374	38,447	66,396
2001	34,374	50,669	28,057	256,286	60,222	40,394	67,494
2002	35,952	51,401	29,328	268,730	62,071	42,341	68,592
2003	37,529	52,132	30,598	281,173	63,919	44,287	69,689
2004	39,106	52,863	31,869	293,617	65,768	46,234	70,787
2005	40,683	53,594	33,139	306,060	67,616	48,181	71,885

Source: GIS Associates, Inc.

2.3 Weather

We collected and calculated four different measures of daily weather:

- Maximum temperature
- Evapotranspiration
- Effective precipitation
- Net irrigation requirement

For each utility, the District provided daily temperature and rainfall over the study period. Temperature values came from nearby National Oceanic & Atmospheric Administration (NOAA) weather stations. Precipitation values were developed from 2-km-square grid observations, developed by OneRain, and averaging those values over each service area.

Evapotranspiration (ET) measures the depth of water evaporated and transpired from a reference crop (grass) when water supply is not limiting. ET is typically calculated for farmers to assist them with irrigation scheduling, but it also provides a good measure of the irrigation demands of homeowners. ET is usually based on advanced formulas (e.g., Penman-Monteith) that include wind speed, solar radiation, relative humidity, and temperature inputs. A difficulty in using ET is that few weather stations calculate ET in Florida, relative to the number with temperature data.

Equations are available, however, where ET estimates can be calculated solely as a function of temperature.

This study utilized the Hargreaves formula to calculate ET, following results derived in a District study that compared alternative formulas (Jacobs et al., 2001). The working equation is:

$$ET = 0.0135 * [Krs * Ra * (Tmax - Tmin)*0.5] / \lambda * (Tave+17.8) * 0.0394$$

where

ET = reference evapotranspiration, inches/day
Krs = adjustment coefficient for mean monthly relative humidity, 0.19
Ra = extraterrestrial radiation determined by latitude and day of year, MJ/m2/day
Tmax = maximum daily air temperature, C
Tmin = minimum daily air temperature, C
λ = latent heat of vaporization, 2.45 MJ/kg
Tave = mean air temperature, C

Because precipitation can be both frequent and large in magnitude, not all can be stored and used by landscapes—some is lost as runoff or percolates past the root zone. Hence, we use a detailed daily soil-moisture model to convert precipitation into effective precipitation (Jensen et al., 1990).

The model assumes that up to 0.315 inches of rain is stored in the soil from a rain event, on average. This assumes a root depth of 5.9 inches (150 mm), 11% water content (sandy loam), and a 50% average management-allowed depletion rate. On average, 50% to 58% of rainfall is effective in offsetting ET.[1]

Lastly, we created a net irrigation requirement (NIR) variable that equaled ET minus effective precipitation. NIR provided us with an overall indicator of the theoretical supplemental water need of landscapes.

2.4 Local Utility Conditions

Factors other than population and weather changes can influence the efficacy of irrigation restrictions. This section summarizes these possible factors.

It is logical to expect differences in irrigation-restriction water savings, depending on:

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[1] This was somewhat higher than our expectations of about 40% effective. We believe this resulted from working with 2x2 km rainfall data. These data represented average rainfall over this large area and proved to be less volatile than rainfall measured at a single-point station.

- Communication of the irrigation restrictions to water users
- Enforcement of penalties associated with non-compliance with the irrigation restrictions
- Magnitude of outdoor irrigation supplied by potable water utility sources
- Good will of people to follow the restrictions to help the community

Each utility used different communication and enforcement tactics. Some utilities focused efforts on customer education. Others instituted a series of monetary fines associated with restriction violations. Local water utilities were responsible for implementing and enforcing the District irrigation restrictions. Because utility service areas do not always follow clear political boundaries, a mix of entities took responsibility for irrigation-restriction implementation.

With some utilities, outdoor irrigation comprises a bigger share of total water use. This occurs when customers have few source substitutes (easy access to shallow aquifers, surface waters, or reclaimed wastewater) and where water is relatively inexpensive. Wealthier communities also tend to use more water for irrigation. We would expect the total percentage reduction to be greater with these high-irrigation utilities, all else held constant.

Customer good will is difficult to quantify but can be an important driver to determine the response to irrigation restrictions. If customers support the goal of reducing water use (e.g., as part of their civic duty), water reductions can be significant. If customers do not view the cause as worthy or necessary, then water savings will be less.

In summarizing local utility conditions, we also need to look at water prices and source substitutes. Significant changes in water and sewer prices can alter water use. Some utilities changed their rate structure to a more water-conserving rate structure (i.e., increasing block rates) during the study period. In addition, some utilities significantly increased water prices in response to the drought and lower water consumption. Hence, we need to consider changes in water and sewer prices, as these can influence customer water use. We do not want to wrongly ascribe water savings caused by pricing to our estimated impact of irrigation restrictions. Measuring pricing effects is complex and beyond the scope of this work. We looked at water and sewer prices, however, as part of our analysis to see if pricing might be a relevant factor.

The increasing use of reclaimed water as a substitute for potable water for irrigation is also a complication. When analyzing total water production, this substitution can entangle and confound quantification of the irrigation-restriction impact.

Table 2-2 presents our observations of local utility conditions associated with the evaluation of irrigation restrictions. These observations were consulted in developing estimates of water savings caused by irrigation restrictions in Chapter 4. Appendix B contains additional details of utility-specific circumstances.

Table 2-2. Local Utility Conditions	
Utility	**Description**
Apopka	Adopted SJRWMD restrictions in 2001. Enforced restrictions, including 437 courtesy warnings, 71 written warnings, six $50 fines, and one $100 fine in 2001. Continuing enforcement. The population increase from 1997 to 2004 (29%) was in line with growth in total customer accounts (31%) over same period. Commercial accounts grew comparatively fast (79%), relative to residential (28%). Changed water and sewer rate structure in November 2001. Water price over 15 TG per month increased 64% after adjusting for inflation. Sewer rate went from flat rate to quantity charge for first 12 TG per month. Reclaimed wastewater use increased significantly.
DeLand	Adopted ordinance 5/21/01. Worked with Volusia County Alliance for enforcement.
Ocoee	Adopted ordinance 2/01, with enforcement starting 4/01. Enforcement by city employees and police department. Included financial penalties. Water rates stable over the study period; they did change briefly 4/98 to 12/98, but returned. Significantly increased 10/03, but end of study period was 12/03.
Orange County	Adopted ordinance 5/22/01. First violation: door-hanger information. Second violation: door-hanger warning. Third violation: notice of violation from code enforcement. Water rates did not change over period.
Port Orange	Adopted irrigation restrictions 9/18/2001. Enforced restrictions. 480 sites provided written warnings; some multiple warnings at same site. From 1997 to 2004, population increased 21%, and total accounts increased by 21%. Inflation adjusted water prices for 8 TG or less reduced, while water prices above 11 TG increased by 31%.
Sanford	Adopted ordinance.
Winter Park	Adopted ordinance. Notices to violators with third citation resulted in code enforcement.
Seminole County	Adopted ordinance in 1/01. First, warning; second, $100 fine; each additional violation, add $100. Trained 31 enforcement staff. From 2/01 to 3/02 issued 79 warnings, 49 $100 fines, and two $200 fines. Non-residential customers irrigated on Tuesday and Friday. Water rates did not change over study period.

3. WATER-USE ANALYSIS

This chapter describes the analysis of daily water production and monthly water billing data. The objective was to quantify the water change that occurred after implementation of the irrigation restrictions. The next chapter summarizes the results and develops inferences on how irrigation restrictions influence water use.

3.1. Water-Production Model

We analyzed the time series of daily GPCD for six utilities. Based on the analysis, we determined that the best model to explain water use in the pre-restriction period 1997–2000 is:

$$GPCD_t = \alpha * MONTH_m * DAYOFWEEK_d + \beta 1 * NIRDEV_t + \beta 2 * NIRDEV_{t-1}$$

where

$GPCD_t$	=	gallons per capita day for day t, utility water production divided by annual population
α	=	mean GPCD over the pre-restriction period 1997 to 2000
$MONTH_m$	=	mean ratio of GPCD in month m to α, m from 1 to 12
$DAYOFWEEK_d$	=	mean ratio of GPCD on day-of-week d to α, d from 1 to 7
$NIRDEV_t$	=	deviation in net irrigation requirement (NIR) on day t from its monthly average, inches per day
$\beta 1$, $\beta 2$	=	coefficients estimated using multiple regression

3.1.1. Monthly Water-Use Ratios

The monthly ratios for each utility are shown in Figures 3-1 to 3-6. Also shown in each figure is a comparable NIR ratio for that month.[2] It is obvious that GPCD and NIR are highly correlated.

[2] The NIR ratio equaled the monthly average of daily NIR for that month, divided by the annual average of daily NIR. An NIR ratio greater than 1 occurred when NIR in that month was greater than its annual average.

Figure 3-1. Apopka Monthly Ratio from 1997 to 2000

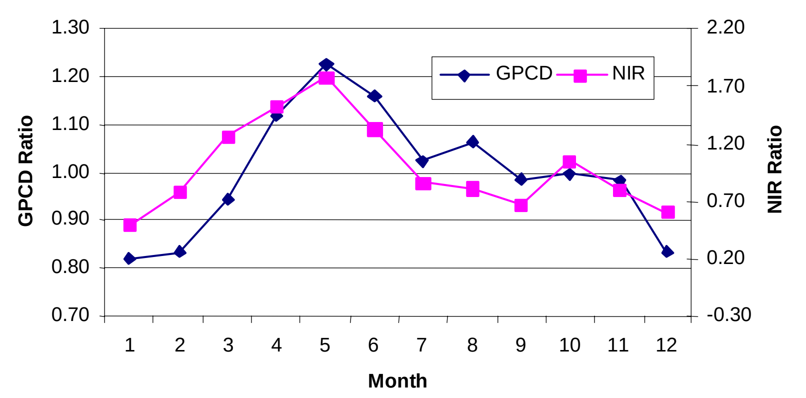


Figure 3-2. DeLand Monthly Ratio from 1997 to 2000

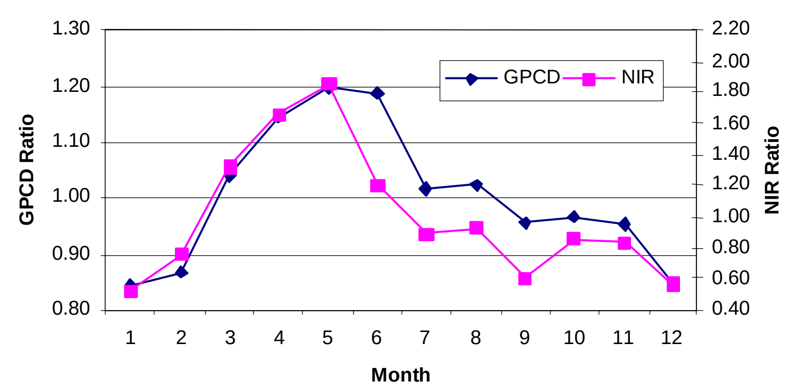


Figure 3-3. Ocoee Monthly Ratio from 1997 to 2000

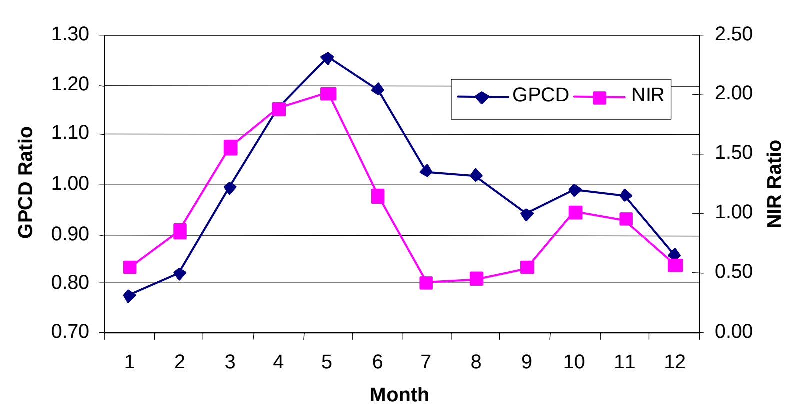


Figure 3-4. OCU Monthly Ratio from 1997 to 2000

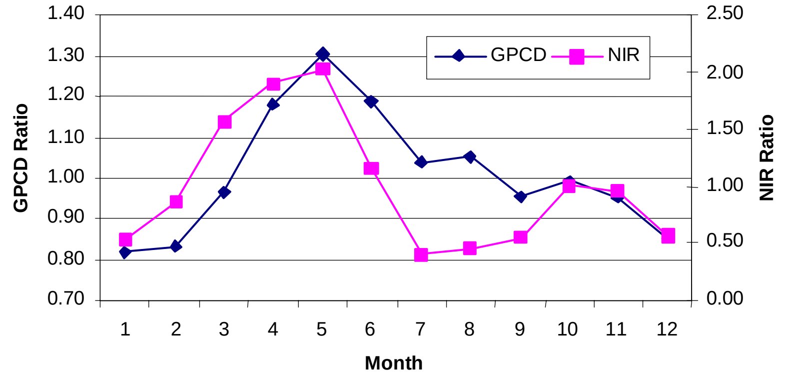


Figure 3.5. Port Orange Monthly Ratio from 1997 to 2000

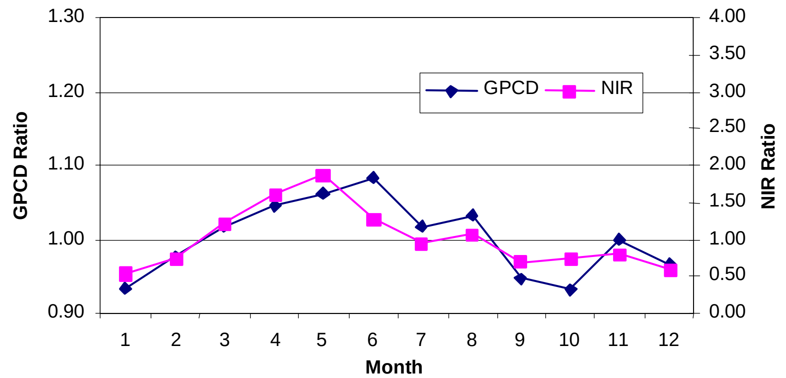
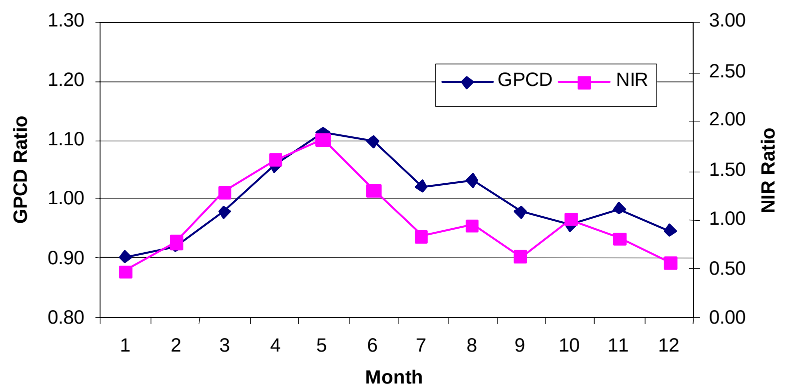
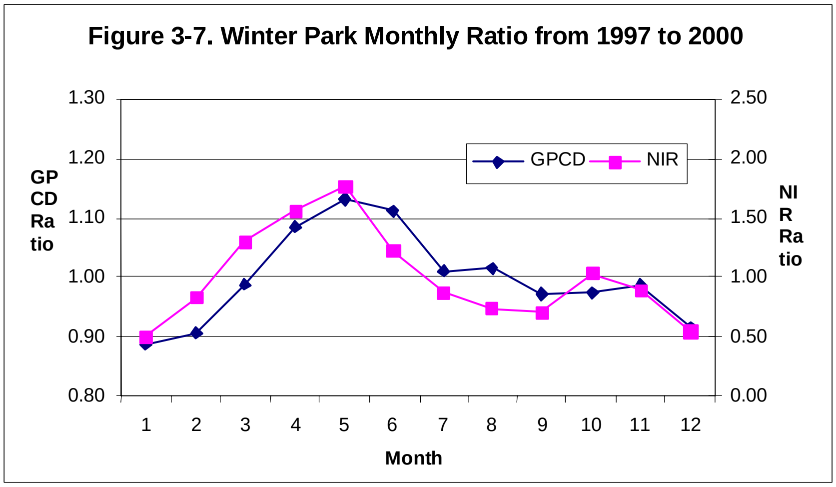


Figure 3.6. Sanford Monthly Ratio from 1997 to 2000





We do note, however, that GPCD and NIR were not perfectly correlated. Although NIR was a good proxy of efficient irrigation, many people used automatic irrigation timers that frequently were not recalibrated to follow variations in weather.[3] We also suspect that non-weather factors, such as seasonal residents, can distort the direct relationship.

Consequently, we employed the MONTH variable, based on historical water use, to more accurately capture the seasonal pattern in water use. As described in a later section, we explain deviations in water use from these monthly ratios as a function of deviations in NIR from its monthly norms.[4]

3.1.2. Day-of-Week Water-Use Ratios

The DAYOFWEEK variable captures the day-of-week pattern in a similar fashion as the MONTH variable. Figure 3-8 plots this variable for each utility. The utilities experienced relatively modest day-of-week differences in water use in the pre-restriction period. DeLand had the most pronounced day-of-week pattern, with water use on Tuesday and Wednesday tending to be above other days.

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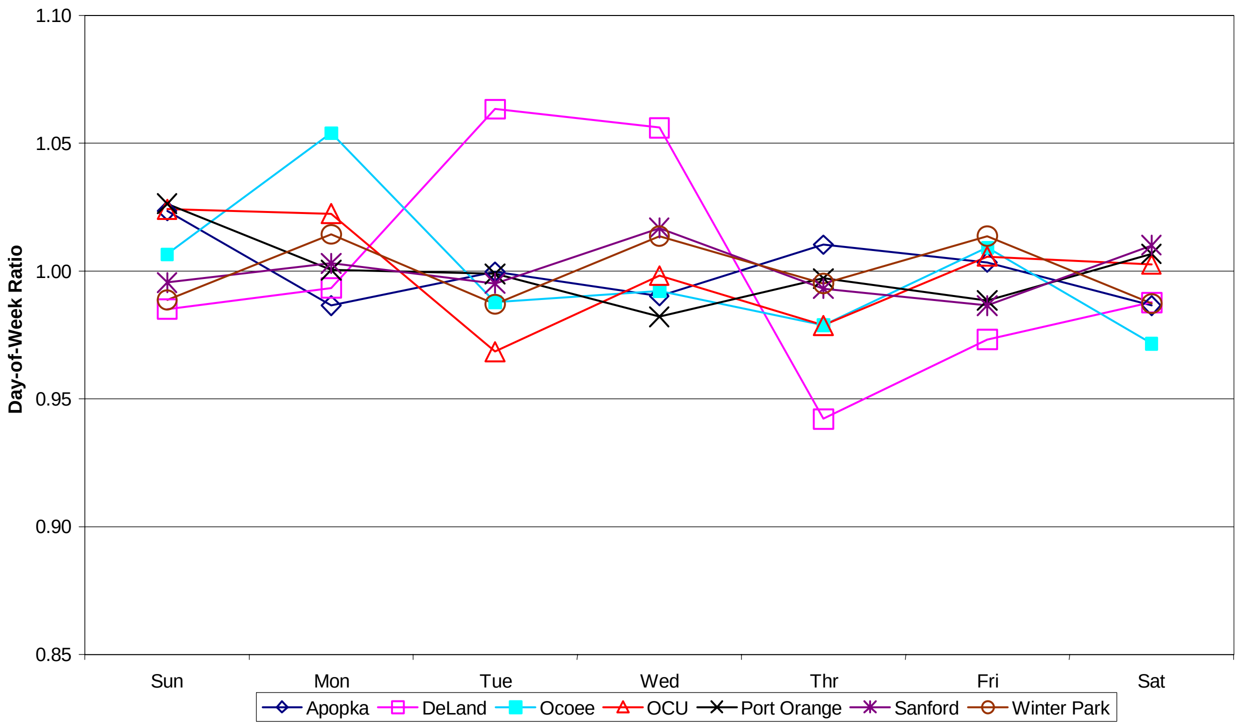
[3] We observed that water use in June, July, and August tended to be higher at all six water utilities than NIR would suggest. This may suggest that people leave their automatic irrigation timers running, regardless of rainfall—more rain tends to fall during these months.

[4] This approach follows J.A. Smith, A Model of Daily Municipal Water Use for Short-Term Forecasting, Water Resources Research, 24(2): 201-206, 1988.

Figure 3-8. Day-of-Week Ratios
Pre-Irrigation Restriction (1997-2000)



3.1.3. Weather Variables

We used multiple linear regression to mathematically define the correlation between daily deviations in NIR from its average monthly values (NIRDEV), and daily deviations in water use from its calendar pattern (established using the MONTH and DAYOFWEEK structure). We also investigated using maximum temperature and precipitation as weather variables, but NIR outperformed the others in its ability to explain water use.

We found a strong statistical correlation, as measured by coefficients $\beta 1$ and $\beta 2$. The $\beta 1$ coefficient measured the impact of the current day's NIR on the current day's water production. The $\beta 2$ coefficient measured the impact of the previous day's NIR on the current day's water production. In many cases, people who irrigated in the morning (e.g., 4 a.m. to 8 a.m.) responded to the previous day's soil moisture conditions, to the extent that they responded at all to weather. In addition, we analyzed daily water production measured at treatment plants. We found that some water systems used short-term storage to meet peak needs and subsequently pump water to replenish storage used in the previous day.

Table 3-1 shows the weather model coefficients. Both the current day's and previous day's NIR deviations were significantly correlated with the current day's water production at all utilities. We also considered longer NIR time lags, but found they did little to help explain water use. Hence, we used these two variables to control for weather. The weather models' ability to explain water use is shown using the R2 statistic.[5] The models did relatively well in explaining water use. The R2 values with Port Orange and Sanford are lower than with the other utilities, but these two utilities also used the least amount of irrigation from this source (utility potable water supplies).

Table 3-1. Weather Model Coefficients

Utility	β1 ($NIRDEV_t$)			β2 ($NIRDEV_{t-1}$)			Model R2
	Coefficient	T-Ratio	P-Value	Coefficient	T-Ratio	P-Value	
Apopka	250.38	21.87	<0.001	111.49	21.9	<0.001	0.5025
DeLand	113.22	12.92	<0.001	79.71	9.10	<0.001	0.3237
Ocoee	46.16	7.04	<0.001	142.31	21.71	<0.001	0.4719
OCU	64.95	4.62	<0.001	186.76	13.25	<0.001	0.3372
Port Orange	14.06	2.28	0.011	45.39	7.35	<0.001	0.0917
Sanford	55.58	5.29	<0.001	64.54	6.14	<0.001	0.1155
Winter Park	62.52	6.25	<0.001	200.45	20.02	<0.001	0.4144

T-Ratios and P-Values indicate that all coefficients are statistically greater than zero with over 99% confidence (T-Ratio greater than 2.33 and P-Values less that 0.01), except for Port Orange, which has a 2.28 T-Value or 98.9% confidence. The model R2 measures the percentage of variation in water use, explained by NIRDEV variables after accounting for the calendar components (month and day of week). Total model R2 values, including the calendar components and weather deviations, are much higher.

[5] R2 measures the variance in water use explained by the weather variables and ranges between 0 and 1. A higher R2 value means the model does a better job. Water use in this case equals actual water use, minus the calendar structure.

3.1.4. Changes in Annual Water Use During Restrictions

After obtaining estimates of water-production model coefficients, the next step was to create predictions of water use without the irrigation restrictions over the period 2001–2004. We used the MONTH and DAYOFWEEK calendar factors and actual daily NIRDEV values to construct the predictions.

Table 3-2 shows the annualized difference between actual GPCD and predicted GPCD without the restrictions. Their difference denotes the water change that occurred after implementation of the irrigation restrictions.

From this perspective, the restriction water changes were greatest with Winter Park, Apopka, DeLand, and Ocoee, where they ranged between -8% and -15%. The water changes with OCU, Port Orange, and Sanford were minor and ranged between -3% and 2%.

Table 3.2. Annualized Water-Use Change After Irrigation Restrictions (2001 to 2004)

Utility	GPCD Actual	GPCD Predicted w/o Restrictions	GPCD Impact	% Change
Apopka	143.6	162.2	-18.6	-11%
DeLand	108.6	122.5	-13.9	-11%
Ocoee	70.4	76.2	-5.9	-8%
OCU	182.3	179.5	2.8	2%
Port Orange	95.8	96.2	-0.4	0%
Sanford	145.4	150.4	-5.0	-3%
Winter Park	160.6	189.4	-28.7	-15%

Actual and predicted water use in GPCD are calculated by month and then annualized to weight each month equally (some utilities have missing month observations).

3.1.5. Changes in Monthly Water Use During Restrictions

Figures 3-9 to 3-15 show actual and predicted water-use values of GPCD by month over the period 1997–2004. We made the following observations for each utility:

- Apopka
  The water production model does a good job of predicting water use over the whole period. Water use significantly dropped over the restriction period.

- DeLand
  Historical water use for May and June 1998 looked high, but closer observation of daily

values during this period did not uncover outlier values with specific days. Water reductions were significant, except for March 2002.

- Ocoee
  There was not much change in water use in 2001. In 2002 and 2003, water use most notably dropped in June through September, suggesting restrictions are most effective in summer months during periods of rainfall. In October 2003, Ocoee significantly increased its water rates and rate structure, making it difficult to ascertain the individual impact of restrictions.

- OCU
  Historical water use in May 1999 did not drop as much as weather suggested it might. The water reductions were significant for 2001 (14.2% from May through September 2001) but erratic thereafter.

- Port Orange
  Water use fluctuated very little during the seasons. This suggests that outdoor irrigation was minimal, as water customers used source substitutes to potable water purchased from the utility (e.g., irrigation wells and reclaimed wastewater).

- Sanford
  Water use fluctuated little during the seasons. Like Port Orange, this suggests that customers irrigated with water sources other than utility water. Water use was unusually high in 2000.

- Winter Park
  The model did a good job of explaining water use. Water use significantly dropped in all restriction months.

Figure 3-9. Apopka Water Production

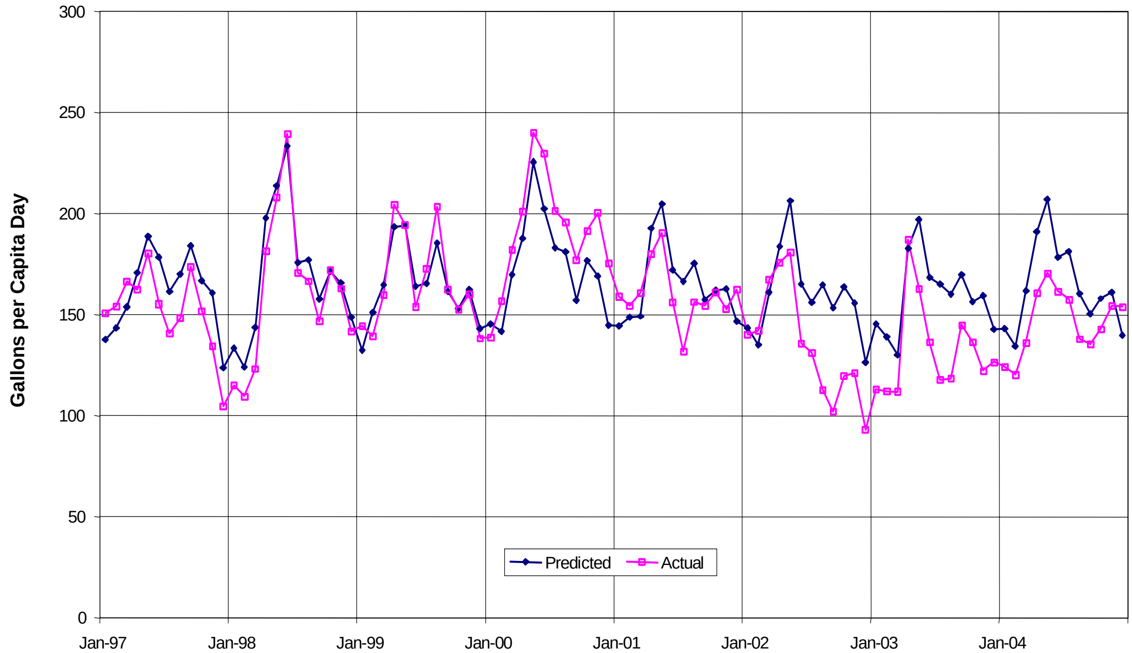


Figure 3-10. DeLand Water Production

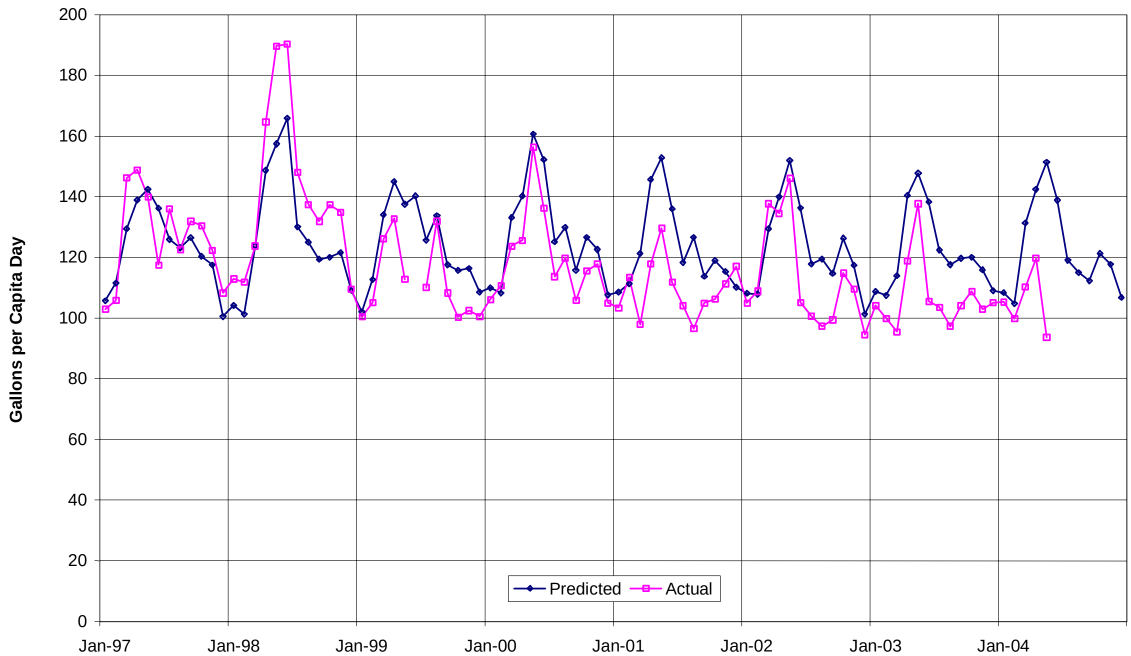


Figure 3-11. Ocoee Water Production

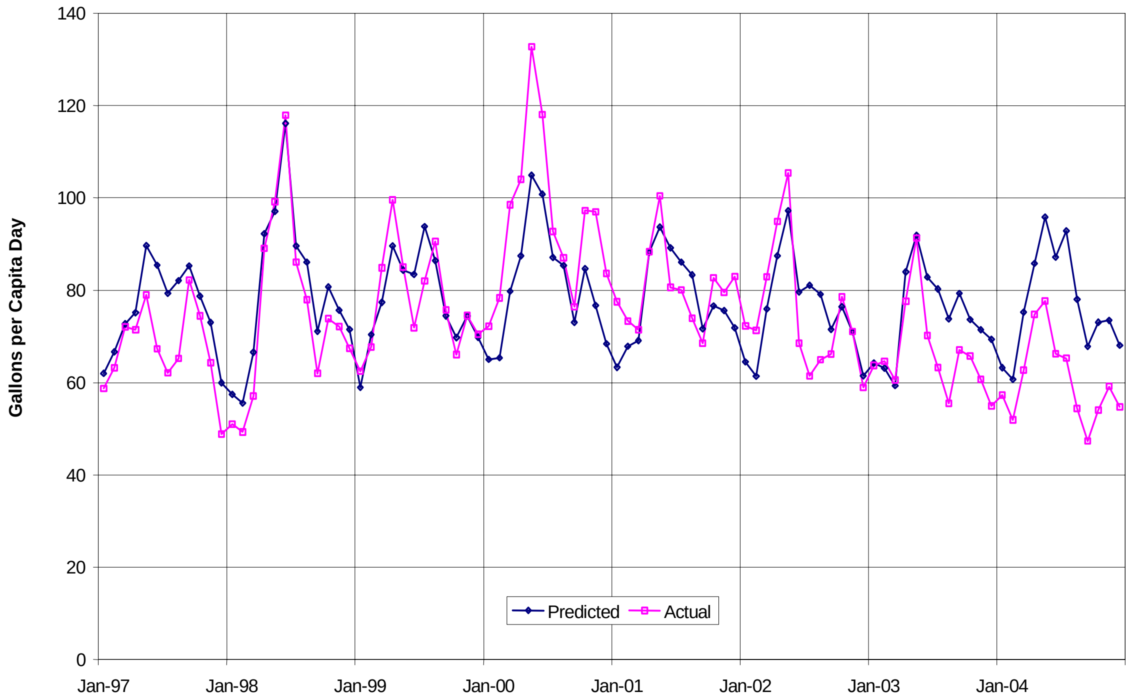


Figure 3-12. OCU Water Production

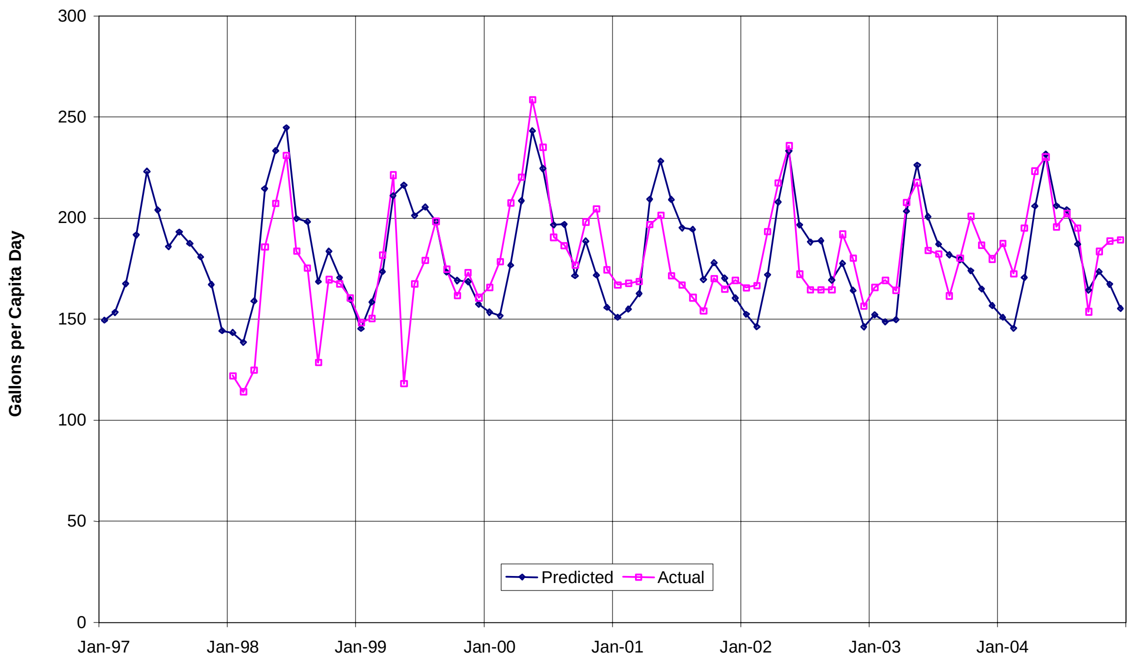


Figure 3-13. Port Orange Water Production

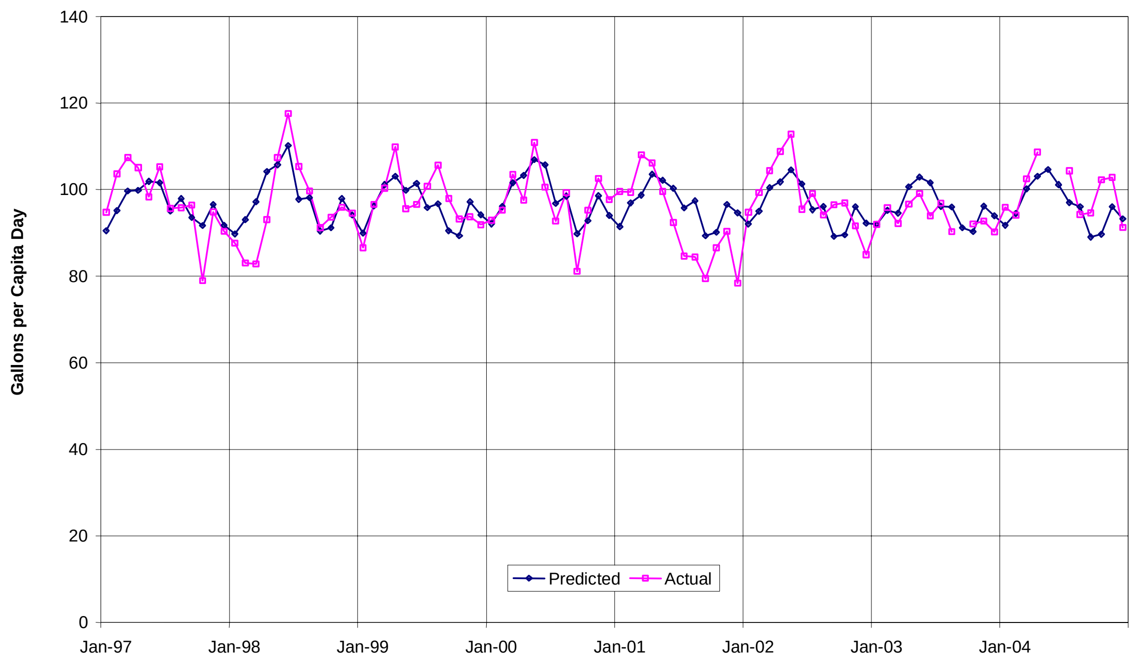


Figure 3-14. Sanford Water Production

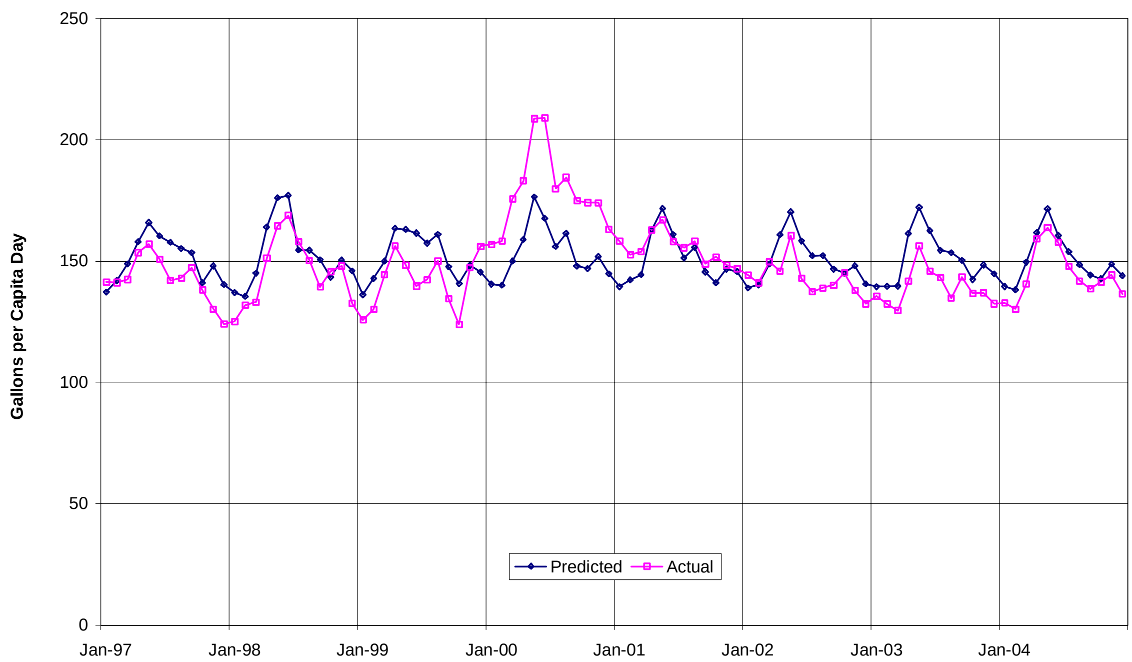
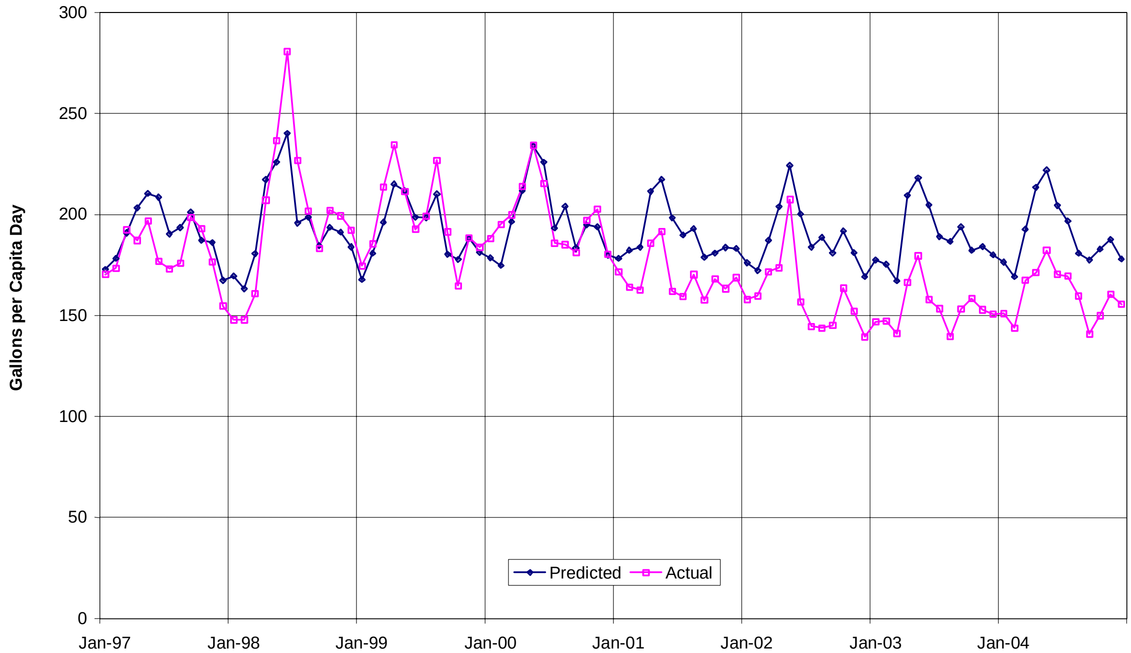


Figure 3-15. Winter Park Water Production

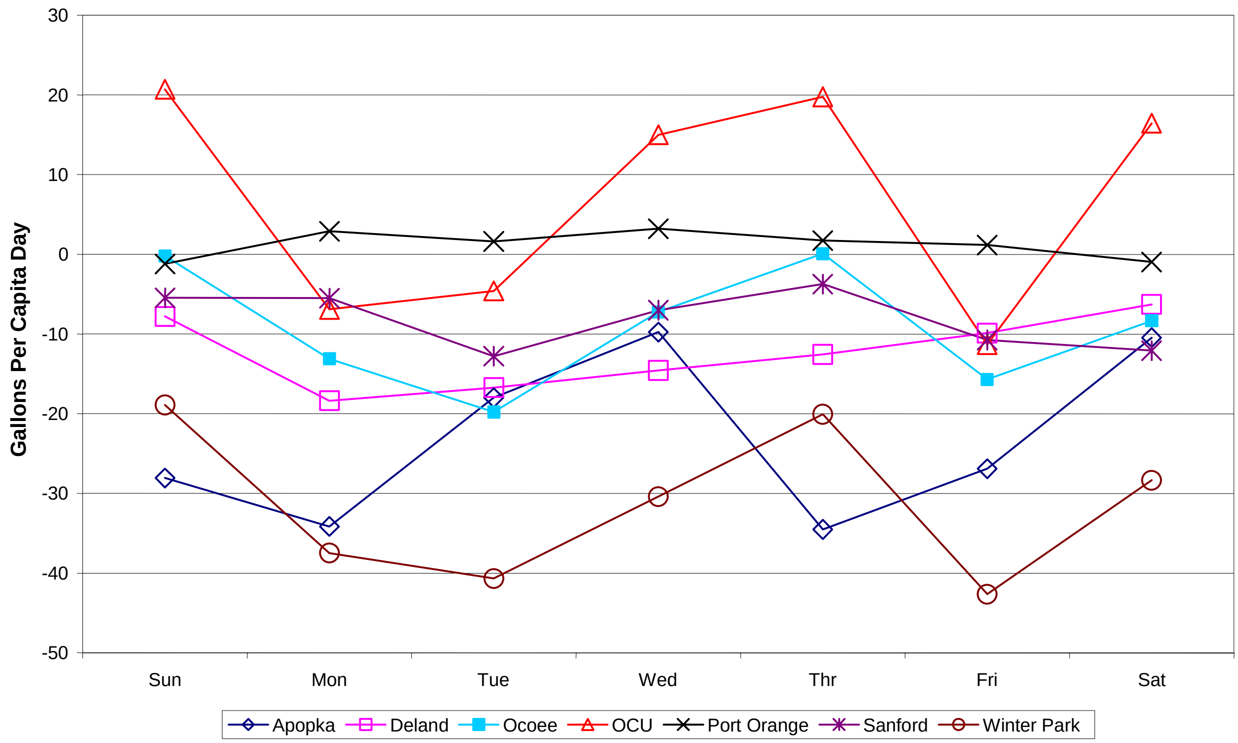


3.1.6. Changes in the Day-of-Week Water Cycle During Restrictions

We found it was informative to investigate changes in the day-of-week pattern, in addition to observing annual and monthly water-use changes that resulted after irrigation restrictions. Because irrigation is allowed on Wednesday and Saturday (odd-number addresses) or Thursday and Sunday (even-number addresses), we postulated that we would see irrigation use increase on these days and drop on Monday, Tuesday, and Friday.

Figure 3-16 shows the change between actual and predicted water use for each day of week.

Figure 3-16. Day-of-Week Change Post-Irrigation Restrictions (2002-2004)



Ocoee and OCU clearly show the expected change in the day-of-week pattern. Water use showed a strong relative increase on Sunday, Wednesday, Thursday, and Saturday—the days when irrigation was allowed. Water use dropped sharply on Monday, Tuesday, and Friday, when irrigation was prohibited. The puzzling finding with OCU is that no annualized water savings were associated with the strong change in the day-of-week pattern. Apparently, customers were complying with the irrigation restrictions, but they were not generating water savings. We do see significant water savings in 2001, but not in 2002, 2003, or 2004.

Port Orange showed no change in the day-of-week water-use pattern. This is as expected, as potable water from the utility for irrigation was minimal and no water savings from the irrigation restrictions were observed.

Sanford, also with minimal potable water irrigation, exhibited a relative drop in water use on Tuesday and, to a lesser degree, on Friday but not on Monday. Hence, the day-of-week change was minimal, corresponding to the relatively modest annual drop in water use (3%).

DeLand experienced its largest relative drop in water use on Monday and Tuesday, as expected, but not on Friday. Water use relatively increased on Saturday and Sunday. Water use on Wednesday and Thursday was less than we expected.

Apopka had a strong change in its day-of-week pattern. For the odd-number street addresses, water use significantly increased on Wednesday and Saturday. For the even-number street addresses, water use did not relatively increase. We are unsure of the cause.

Lastly, Winter Park experienced both the expected change in day-of-week pattern and had a significant reduction in water use (11%).

3.2. Water Billing Data

We analyzed water-billing data from Ocoee and Seminole County to evaluate irrigation restrictions from another angle.[6] The utilities read their customers' water meters on a monthly basis for billing purposes. The readings were made on a revolving basis throughout the month to maximize the efficiency of the water-meter-reading staff.

The disadvantage of evaluating this data is that we could not measure day-of-week changes in water use from monthly records, as could be done when evaluating daily water production. The advantage, however, is that we obtained water-use data for a particular customer class and focused on particular customers within that customer class. Specifically, our approach consisted of analyzing single-family-home water use—this is the largest customer class and was the target of much of the irrigation-restriction education and enforcement. Our approach also included only customers who were served over the entire study period. Hence, we controlled for growth by not including any new homes in our study group. Given the significant growth in population experienced in the region, the potential complexity of controlling for growth was avoided.

In the case of Seminole County, we also focused analysis on the water use associated with irrigation meters used by single-family homes. Irrigation meters are very popular in Seminole County, as customers do not have to pay an associated sewer charge as they do with water recorded through a regular water meter. Focusing on irrigation meters allowed us to directly see how irrigation restrictions affected irrigation water use, without interferences from indoor water uses.

[6] This detailed water-use data was used in a recent statewide study that evaluates how water prices impact water use (Whitcomb, 2005).

3.2.1. Water Billing Data Model

We collected billing data for Ocoee from January 1998 through December 2003 and for Seminole County from January 1998 through October 2003. This period was shorter than it was for data collected for the production model (1997–2004) and included fewer observations because data were on a monthly instead of a daily resolution.

Consequently, we used two different modeling approaches to measure the water change of irrigation restrictions. The first modeling approach was similar to the water-production model described earlier. The second modeling approach included a variable that directly measured the irrigation-restriction impact and was estimated over the entire pre/post-study period (not just the pre-restriction period). The expansion of modeling from the pre-restriction months (36 observations between 1998 and 2000) to the full study period (70 to 72 observations) provided more data for the model to estimate and capture the weather impact.

Both water-use models are defined below:

Model 1: $GPD_m = \alpha + \beta 1 * NIR_m$

Model 2: $GPD_m = \alpha + \beta 1 * NIR_m + \beta 2 * IR_m$

where
GPD_m = average gallons per day for month m
NIR_m = average daily NIR for month m
IR_m = 1 if irrigation restriction effective in month m; 0 otherwise
α, $\beta 1$, $\beta 2$ = coefficients estimated using multiple regression

Because of the revolving monthly billing cycle, we went to great effort to calculate the best unbiased estimate of NIR. The process included developing a matching NIR value for each water-use observation for each customer. Then GPD and NIR averages of all observations that occurred in each calendar month were made. The benefit of this rigorous approach is that water use and weather are exactly matched in time.[7]

[7] We did not assume, for example, that all meter readings were made on the 15th of the month, as that could lead to distortions and time-blurring of the NIR values, with respect to recorded GPD periods.

3.2.2. Results for Ocoee

Our Ocoee dataset included metered water-use observations for about 8,800 single-family homes. Screening out homes with zero or negative (adjusted) water-use readings and homes that did not have a complete water-use history over 1998 to 2003 left 6,332 homes for the analysis.

Figure 3-17 shows average GPD and NIR by calendar month for the study homes. Water use and NIR are highly correlated. Water use during the restriction period was clearly less than the pre-restriction period. Some of this was weather related. NIR peaked in summers 1998 and 2000, coinciding with peak water-using months. The conclusion is that weather must be addressed and controlled for over time in measuring impacts from irrigation restrictions.

Figure 3-17. Ocoee Single-Family Home Water Use from Billing Data

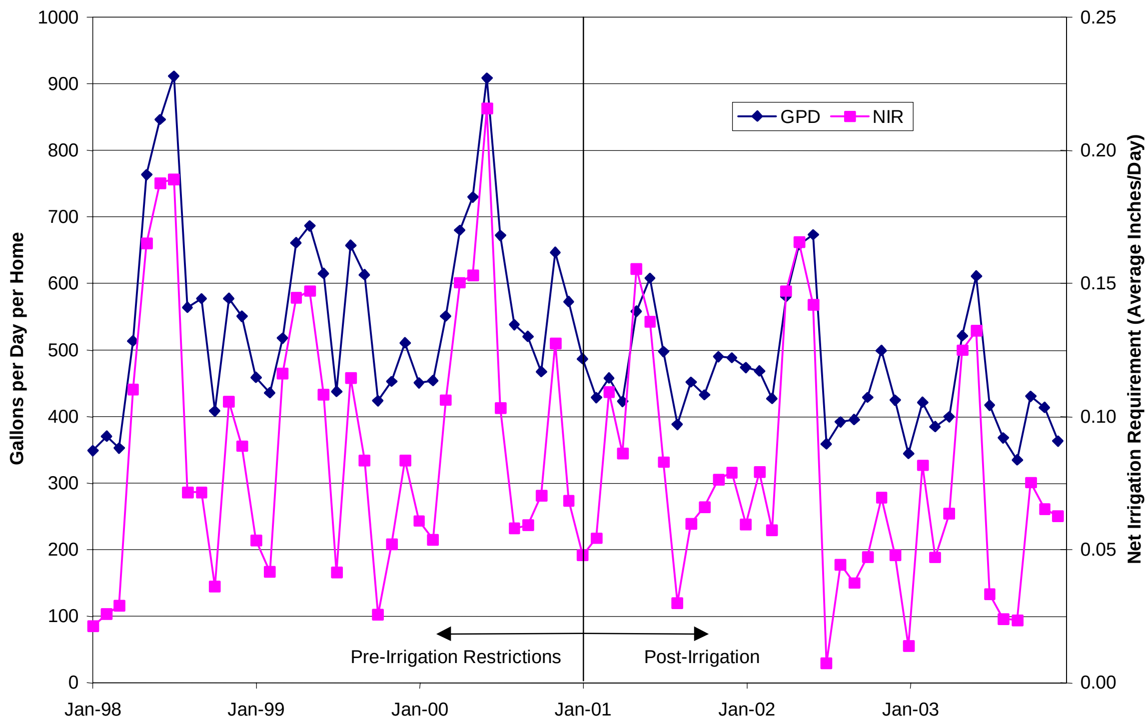


Table 3-3 shows the results for the two water-use models applied to Ocoee. Both models do an excellent job of explaining water-use variations with high R2 values. All of the model coefficients take on their expected mathematical sign and are statistically different from zero.

Model 1 was estimated on pre-restriction data (1998–2000). The model results were then combined with restriction-period weather values to derive a prediction of restriction water use.

Figure 3-18 shows the difference between actual and predicted water use in the restriction period. The water change averaged -60 GPD per home during this period, or 11.6% of total predicted water use. Water savings were higher during the high irrigation periods and lower during the low irrigation periods—an expected result. Results showed the water reductions were persistent over time; water changes in 2001, 2002, and 2003 were -72, -43, and -74 GPD per home, respectively.[8]

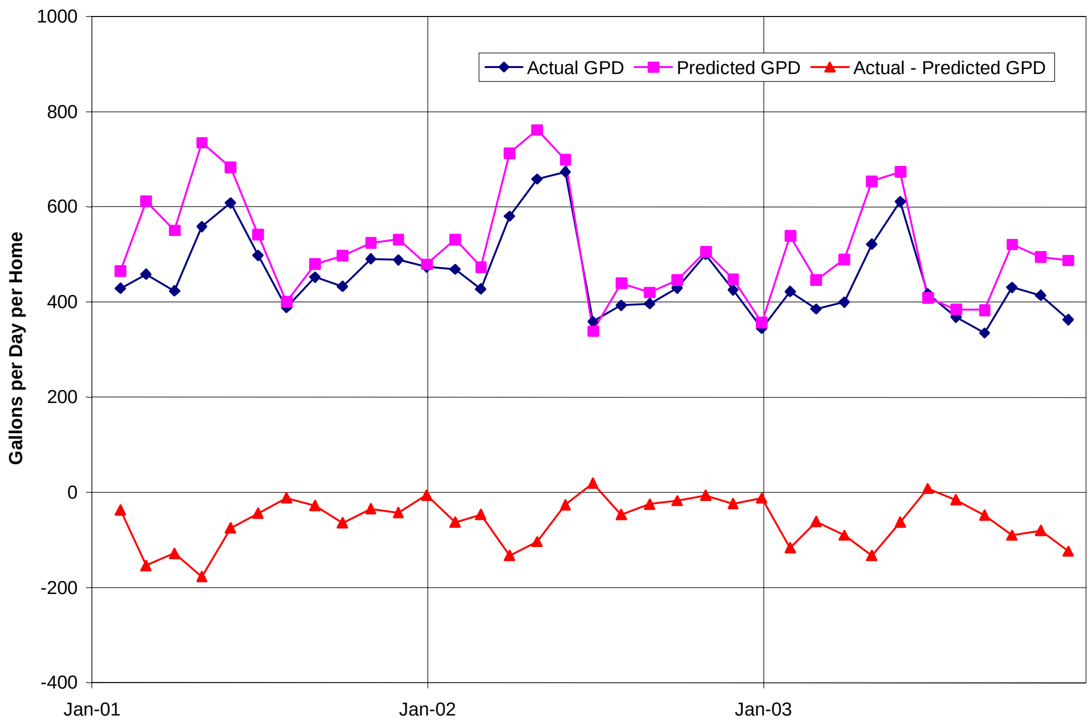
Table 3-3. Ocoee Water-Use Model Results

Description	Model 1			Model 2		
	Coefficient	**T-Ratio**	**P-Value**	**Coefficient**	**T-Ratio**	**P-Value**
Intercept	320.177	19.269	<0.000	350.125	26.648	<0.000
NIR	2670.706	16.975	<0.000	2355.282	20.046	<0.000
IR	--	--	--	-66.538	-6.0479	0.000
Model R2			0.894			0.879
Observations			36			72

T-Ratios and P-Values indicate that all coefficients are statistically greater than zero, with over 99% confidence (T-Ratio greater than 2.33 and P-Values less that 0.01).

[8] We did not use January 2001 in the calculation of water savings, as the irrigation restrictions became effective January 2001. Hence, water savings from February to December in each year were shown to be on a comparable basis.

Figure 3-18. Ocoee Water Change Post-Irrigation Restrictions



Model 2 provides a direct estimate of the restriction water change via the coefficient β2 that was -66.5 GPD per home. This estimate is somewhat larger than the -60 GPD estimate established with Model 1. It is not surprising that the estimates differ to a modest degree, as both models have different assumptions and approaches for measuring GPD water changes. The advantage of Model 1 is that it can generate the detailed month-to-month results, shown in Figure 3-16. One advantage of Model 2 is that the weather impact is established over a longer period; another advantage is that it provides a direct statistical test that verifies the statistical significance of the water-change estimate. The 95% confidence interval of the water-change estimate is -44.9 to -88.1 GPD per home.

3.2.3. Results for Seminole County

The Seminole County dataset included metered water-use observations for about 6,500 single-family-home irrigation meters. The dataset included a field that identified if a site changed account ownership (the Ocoee dataset does not have this field). We screened out homes with changes in ownership (e.g., the house was sold) so that the study group included only homes that existed in 1998 with the same ownership through 2003. We also screened out homes that did not have a complete water-use history over 1998 to 2003, leaving 2,715 homes for the analysis.

Figure 3-19 shows average GPD and NIR by calendar month for the study homes. Water use and NIR are highly correlated. Water use during the restriction period was clearly less than the pre-restriction period. NIR and GPD spiked in the summers 1998 and 2000, again showing that weather must be controlled for in an evaluation of irrigation restrictions.

Figure 3-19. Seminole Single-Family Irrigation Water Use from Billing Data

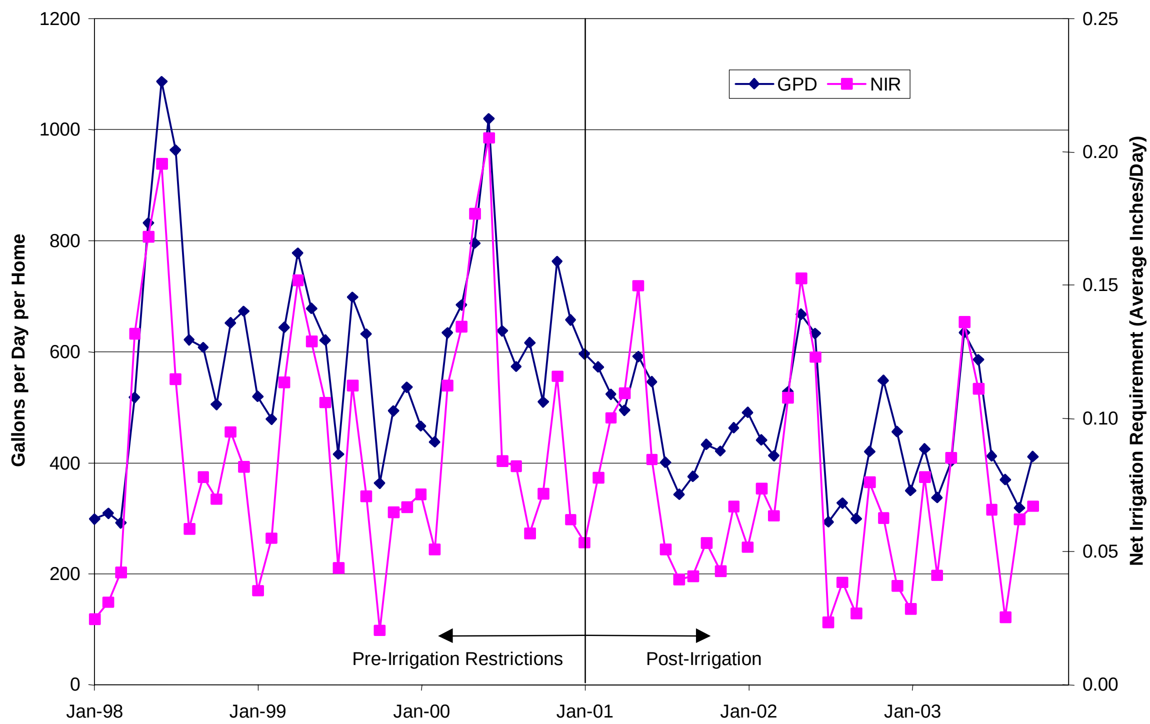


Table 3-4 shows the results for the two water-use models for Seminole County. Both models do a good job of explaining water-use variations with high R2 values. All of the model coefficients take on their expected mathematical sign and are statistically different from zero.

Table 3-4. Seminole County Water-Use Model Results

Description	Model 1			Model 2		
	Coefficient	T-Ratio	P-Value	Coefficient	T-Ratio	P-Value
Intercept	305.533	8.727	<0.000	338.663	13.694	<0.000
NIR	3019.701	9.823	<0.000	2355.282	13.0451	<0.000
IR	--	--	--	-101.453	-5.133	<0.000
Model R2			0.739			0.780
Observations			36			70

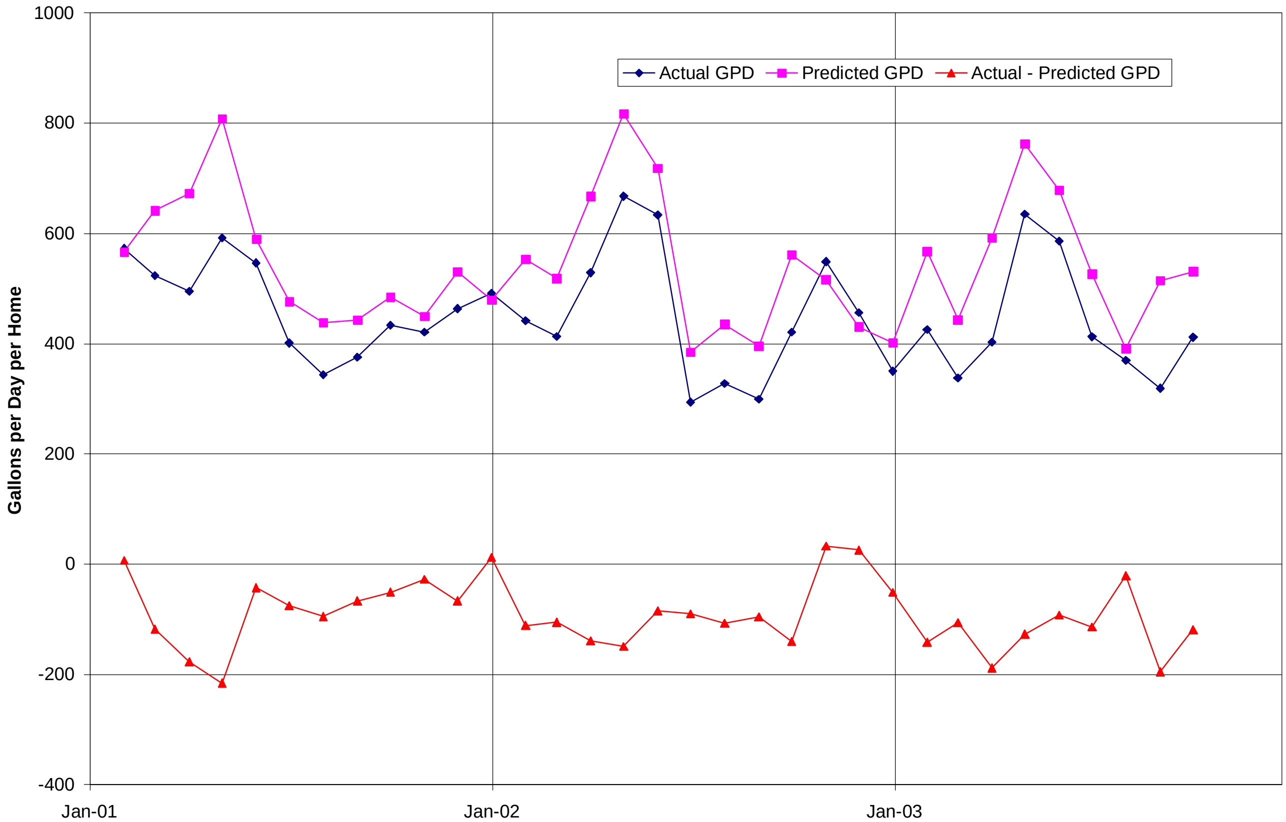
T-Ratios and P-Values indicate that all coefficients are statistically greater than zero, with over 99% confidence (T-Ratio greater than 2.33 and P-Values less that 0.01).

Model 1 is estimated on pre-restriction data (1998–2000). The model results were then combined with restriction-period weather values to derive a prediction of restriction water use. Figure 3-18 shows the difference between actual and predicted water use in the restriction period. The water change averaged -92.1 GPD per home during this period, or -16.9% of total predicted water use. Water reductions tended to be higher during the high-irrigation periods. Results showed that the water changes from February to October in 2001, 2002, and 2003 were -93, -114, and -123 GPD per home, respectively.[9] Hence, water reductions appeared to not be diminishing but growing.

The Model 2 estimate of post-restriction water change via the coefficient β2 was -101 GPD. This estimate was somewhat larger than the -92 GPD estimate established with Model 1. The 95% confidence interval around this estimate is -62.7 to -140.2 GPD.

[9] January 2001 was excluded, as it was largely before the irrigation restrictions took effect. We do not have water use data for November or December 2003. Hence, we used the February-to-October period for comparisons of the years.

Figure 3-20. Seminole Water Change Post-Irrigation Restrictions



4. DISCUSSION OF THE EFFECTIVENESS OF IRRIGATION RESTRICTIONS

This chapter provides an assessment of the water savings caused by irrigation restrictions. It includes a literature review, summary of this study's empirical findings, and future research directions.

4.1. Literature Review

This section provides a review of other studies that evaluate the effectiveness of irrigation restrictions in the United States. This allows us to put the District's results into context with others that have used irrigation restrictions. It also allows us to provide a wider discussion on how irrigation restrictions can be utilized to manage scarce water resources.

The studies reviewed include: [10]

- Fort Collins, Colorado (1977)
- Austin, Texas (1984 and 1985)
- Corpus Christi, Texas (1984)
- Southwest Florida Water Management District, Florida (1988–1992)
- Wekiva River Basin, Florida (1989, 1993, 1994)
- Southern Duval and Northwest St. Johns Counties, Florida (2000)
- Denver Metropolitan Area, Colorado (2002)
- Florida Water Rates Evaluation (1998–2003)

4.1.1. Fort Collins, Colorado

The first reviewed published study addresses irrigation restrictions enforced in Fort Collins, Colorado, in 1977 (Anderson et al., 1980). The City of Fort Collins implemented two-days-per-week restrictions on July 15.

To start, the city used geographic area to determine irrigation eligibility. The city was divided into four geographic zones, with each zone allowed to water on a particular weekday (Monday

[10] The dates in parentheses show the year the irrigation restrictions were in effect.

through Thursday), plus one weekend day (Saturday or Sunday). No watering was allowed on Friday. This scheme, however, was not workable, as water pressure declined to unacceptable levels in the portion of the city that watered on a particular day. On July 27, the city adopted a new scheme based on street address, as shown in Table 4-1. These restrictions were in effect until August 23, 1977, when improved water supplies from heavy rainfall made restrictions unnecessary.

During the restriction period, water use dropped by 41%, relative to the same period in the prior year (1976). Heavy rainfall during the restriction period, however, totaled 8.09 inches, as compared to the normal total of 2.11 inches. The evaluation of daily water-production data concluded that the heavy rain accounted for about half of the experienced reduction in water use—the irrigation restrictions alone caused only a 19.7% reduction.

Table 4-1. Fort Collins Irrigation-Restriction Schedule for 1977

Day of Week Irrigation Allowed	Street Address Ending With
Monday and Friday	3, 5, 8, 9
Tuesday and Saturday	0, 2, 6
Wednesday	No watering
Thursday and Sunday	1, 4, 7

A major conclusion of this study is that weather must be accounted for in any estimate of the water savings associated with irrigation restrictions. This study also points out that irrigation restrictions can adversely influence system water pressure by concentrating irrigation-focused periods.

4.1.2. Austin, Texas

Austin implemented mandatory irrigation restrictions from July 16 to August 18, 1984, and from July 31 to September 12, 1985. An evaluation of daily water-production data resulted in mixed observations about their efficacy (Shaw et al., 1987).

Austin adopted a rather confusing set of irrigation restrictions. In 1984, outdoor watering was restricted to once every five days between certain hours, depending on the last digit of the street address; watering could occur at any time with hand-held hose, bucket, or drip-irrigation system. In 1985, during a more severe drought period, outdoor irrigation was allowed only by hand-held house, bucket, drip-irrigation system, or permanently installed automatic sprinkler system. Public outcry on the fairness of allowing automatic sprinkler systems while prohibiting manual sprinkler systems led to a change in policy and a return to the 1984-type restrictions.

The evaluation estimated the water savings from the restrictions were about 8% in 1984, although the standard error of this estimate was rather high (marginally statistically significant). Moreover, the savings estimate for 1985 was only about 3% and not statistically significant.

We conclude from this study that overly complicated irrigation-restriction policies can confuse customers and lead to lower water savings. A revolving five-day schedule is difficult for customers to remember and implement. The authors of this study also speculate that the “shock effect” of irrigation restrictions can diminish over time, as demonstrated by the lower water savings experienced in 1985, relative to 1984.

4.1.3. Corpus Christi, Texas

This study investigated the water reduction from a set of interventions made by the City of Corpus Christi in 1984 (Shaw et al., 1988). The evaluation was based on daily water-production records that used the same methods as were used in Austin.

The interventions included a voluntary stage, which asked customers to limit outdoor irrigation to every other day. This stage was in effect from May 17 to July 1. Results showed no savings with this tactic.

The second stage occurred July 1 to August 25 and mandated that outdoor irrigation could occur only once every 10 days, when the last digit of a customer’s street address matched the last digit of the calendar date. Watering was allowed with a hand-held hose, bucket, or drip-irrigation system, or attended sprinkler system. Results show that water use decreased by 31%, relative to what it would have been otherwise, based on a water-use model.

The third stage occurred from August 25 to October 30 and included a total ban on outdoor irrigation and a punitive water-rate schedule. Water use decreased by 39%, relative to what water use would have been. A significant amount of the decrease came from large industrial customers in their base demand (not outdoor irrigation), likely motivated by the water-rate change.

This study concludes that voluntary irrigation restrictions have little impact, and severe irrigation restrictions (once in 10 days) can dramatically decrease water use.

4.1.4. Southwest Florida Water Management District, Florida

This study analyzed the monthly water use of individual homes served by 10 water utilities within the Southwest Florida Water Management District between 1988 and 1992 (Brown and Caldwell, 1999). The primary purpose of the study was to quantify the relationship between water use and water prices, but impacts of irrigation restrictions were addressed and controlled for by water-use models. Results show that two-days-per-week restrictions did not reduce water use in three of four models estimated. In contrast, one-day-per-week restrictions correlated with reduced outdoor water use in all cases.

4.1.5. Wekiva River Basin, Florida

The District funded a study to assess the water savings from water restrictions during summer 1989, and from summer 1993 to summer 1994 (Post, Buckley, Schuh & Jernigan, 1997). This study did not document details of the restrictions used. It did evaluate and conclude that the water savings were not significant. It evaluated weekly water production for the City of Apopka and the privately owned Sanlando Utilities, using water-use models to control for weather impacts.

4.1.6. Southern Duval and Northwest St. Johns Counties

The District issued an emergency order (Emergency Order for No. 2000-13) that mandated irrigation restrictions for portions of southern Duval County and northwest St. Johns County, effective May 18 to August 9, 2000, because of drought. Irrigation was restricted to two days per week, depending on street address, and prohibited between 10 a.m. and 4 p.m. The District funded a study to quantify the effectiveness of the restrictions (Barnes, Ferland and Associates, 2001). This study analyzed weekly totals of daily water production over several years; water-use models controlled for weather impacts.

Table 4-2 summarizes the findings. This study suffered from data deficiencies and research design. The Community Hall Water Plant analysis was corrupted because the Jacksonville Electric Authority plants are interconnected, and water use from other service areas that are not subject to the restrictions could not be separated. Water use increased by 8.8% after the restrictions, a result undoubtedly caused by the interconnection issue. Water production from the Remington Forest Water Plant declined 2.8% after the restrictions, but this plant is extremely small, serving about 80 customers. The United Water Florida area was not studied, as only monthly data (instead of weekly) were obtained.

This study also investigated the water savings associated with the irrigation restrictions adopted by the Gainesville Regional Utilities during 2000 (but not mandated from the District). Water use increased by 0.3% after the restrictions.

Table 4-2. Irrigation-Restriction Water Savings from Barnes, Ferland and Associates	
Utility	**Water Savings**
Jacksonville Electric Authority – Community Hall Water Plant	Water use increased 8.8%.
Remington Forest Water Plant	Water use decreased 2.8%. Only 80 customers.
United Water Florida	Provided monthly data that was not analyzed.
Gainesville Regional Utilities	Water use increased 0.3%. Adopted different restrictions than others.

The authors note that irrigation restrictions can significantly increase water use on the days irrigation is allowed, which sometimes adversely decreases water pressure in the system. This study did not address potential impacts from reclaimed wastewater, water rates, or customer growth (except with Gainesville).

4.1.7. Denver Metropolitan Area, Colorado

This study evaluated the water savings from irrigation restrictions at eight utilities during 2002 (Kenney et al., 2004). The study was based on evaluation of daily water-production records from 2000 to 2002.

The utilities used a mix of voluntary and mandatory irrigation restrictions. Restrictions spanned limiting irrigation from three days to one day per week. Restrictions were in place from May through August.

As shown in Table 4-3, water savings associated with voluntary restrictions (ranging 4–12%) were less than with mandatory restrictions (ranging 18–56%). Water savings associated with more stringent mandatory restrictions saved more water.

Table 4-3. Irrigation-Restriction Water Savings in Colorado from Kenney et al

Utility	Days-per-Week Irrigation Allowed	Water Savings on Expected Per Capita Basis	
		Voluntary Restriction Period	Mandatory Restriction Period
Aurora	3	--	18%
Denver Water	3	7%	21%
Thornton	3	10%	--
Westminster	3	11%	27%
Boulder	2	4%	31%
Fort Collins	2	12%	24%
Louisville	2	--	45%
Lafayette	1	--	56%

The authors note that each utility has a different mix of customer types (e.g., residential, commercial, industrial), and hence, comparing water production among utilities is difficult. They also note that utilities used different strategies related to water-conservation public campaigns, water-rate increases, and enforcement of restrictions. The 2002 drought was one of the most severe on record, and the irrigation restrictions had the general support and good will of the people as a temporary means to respond to emergency conditions. Part of the response included utilities' postponing system flushing and maintenance to save water, as well as limiting the water applied to public parks and landscapes.

4.1.8. Florida Water Rates Evaluation of Single-Family Homes

The objective of this evaluation was to analyze monthly water-use billing records of single-family homes at 16 water utilities in Florida from 1998 to 2003 to ascertain the relationship between water use and water price (Whitcomb, 2005). It is the largest study ever conducted of this type.

To isolate pricing effects, the study needed to control for the impact on water use from irrigation restrictions. Table 4-4 shows the type of restrictions in place for the nine utilities affected by irrigation restrictions.

Table 4-5 shows the percentage reduction in average water use associated with two circumstances and for four home profiles. Profiles 1, 2, 3, and 4 represent the 25th, 50th, 75th, and 90th percentile homes by property value on a statewide basis. The first circumstance occurred when irrigation was restricted from two days to one day per week. Utilities within the Southwest Florida Water Management District experienced this circumstance during a drought period that started March to May 2000 and continued for different lengths of time at each utility. When the one-day restriction was not in effect, a two-day restriction was in effect over the study period for all these utilities. Average water reductions associated with going from two-day to one-day restrictions ranged from 9% to 20%, and tended to be higher for the profile 3 and 4 customers. Lakeland experienced less of a reduction than other utilities—profile 2 actually shows a 10% increase in water use.

Table 4-4. Irrigation Restrictions with Florida Water Rates Evaluation

Utility	Irrigation Restrictions
Hillsborough	Jan-98 to Mar-00: 2 days per week, not between 9 a.m. and 5 p.m. Mar-00 to Nov-03: 1 day per week, not between 8 a.m. and 6 p.m. Nov-03 to Dec-03: 2 days per week, not between 8 a.m. and 6 p.m.
Lakeland	Jan-98 to May-00: 2 days per week, not between 10 a.m. and 4 p.m. May-00 to Nov-01: 1 day per week, not between 10 a.m. and 4 p.m. Nov-01 to Dec-03: 2 days per week, not between 10 a.m. and 4 p.m.
Ocoee	Jan-98 to Dec-00: not between 10 a.m. and 4 p.m. Jan-01 to Dec-03: 2 days per week, not between 10 a.m. and 4 p.m.
Palm Beach	Jan-98 to Mar-01: not between 9 a.m. and 5 p.m. Dec-00 to Jan-01: 3 days per week, not between 9 a.m. and 5 p.m. Feb-01 to Oct-01: 2 days per week, not between 8 a.m. and 4 a.m. Nov-01 to Dec-03: not between 9 a.m. and 5 p.m.
Sarasota	Jan-98 to May-00: 2 days per week, not between 10 a.m. and 4 p.m. May-00 to Dec-03: 1 day per week, not between 10 a.m. and 4 p.m.
Seminole	Jan-98 to Dec-00: not between 10 a.m. and 4 p.m. Jan-01 to Dec-03: 2 days per week, not between 10 a.m. and 4 p.m.
Spring Hill	Jan-98 to May-00: 2 days per week, not between 10 a.m. and 4 p.m. May-00 to Nov-01: 1 day per week, not between 10 a.m. and 4 p.m. Nov-01 to Feb-03: 2 days per week, not between 10 a.m. and 4 p.m. Mar-03 to Jun-03: 1 day per week, not between 10 a.m. and 4 p.m. Jul-03 to Dec-03: 2 days per week, not between 10 a.m. and 4 p.m.
St. Petersburg	Jan-98 to Apr-00: 2 days per week, between 5-9 a.m. and 7-11 p.m. Apr-00 to Oct-03: 1 day per week, between 5-9 a.m. and 7-11 p.m. Oct-03 to Dec-03: 2 days per week, between 5-9 a.m. and 7-11 p.m.
Tampa	Jan-98 to Mar-00: 2 days per week, not between 9 a.m. and 5 p.m. Mar-00 to Nov-03: 1 day per week, not between 8 a.m. and 6 p.m. Nov-03 to Dec-03: 2 days per week, not between 8 a.m. and 6 p.m.

The second circumstance had three utilities (Ocoee, Palm Beach, and Seminole) that ranged from no restrictions to two-days-per-week restrictions. The restrictions started at the beginning of

2001 and extended for varying lengths of time. For Ocoee and Seminole County, the restrictions stayed in place for the entire period (and are still in effect). For Palm Beach County, restrictions were lifted in October 2001. Model results show that the intervention of going to two-days-per-week restrictions correlates with an average 11% to 19% reduction in water use.

Table 4-5. Irrigation-Restriction Reductions from Whitcomb 2005 Study

		Profile			
Utility	**Days per Week Irrigation**	**1**	**2**	**3**	**4**
Hillsborough	2 to 1	-7%	-4%	-17%	-19%
Lakeland	2 to 1	-6%	10%	-8%	-2%*
Sarasota	2 to 1	-1%*	-5%	-16%	-23%
Spring Hill	2 to 1	-2%*	-29%	-21%	-23%
St. Petersburg	2 to 1	-24%	-15%	-5%	-33%
Tampa	2 to 1	-14%	-13%	-23%	-21%
Average	2 to 1	-9%	-9%	-15%	-20%
Ocoee	7 to 2	-14%	-5%	-10%	-13%
Palm Beach	7 to 2	-23%	-20%	-21%	-19%
Seminole	7 to 2	NA	-8%	-16%	-23%
Average	7 to 2	-19%	-11%	-16%	-18%

Results applicable to homes without irrigation source substitution. In Lakeland, administrative difficulties during restriction period may have limited enforcement.
* Denotes estimates not statistically different from zero (95% confidence).
NA = Not applicable, as no homes for this utility/profile.

4.1.9. Summary of Literature Review

Irrigation restriction is an available tool for water managers to reduce water use during times of water shortage. Restrictions are typically applied during periods of drought, when the compounding circumstances of decreasing water supplies and increasing irrigation water demands exist.

The history of reducing water use via irrigation restrictions is mixed. In some cases, irrigation restrictions can cause water-use reductions over 50%. In other cases, irrigation restrictions might actually increase total water usage—some customers irrigate on allowed days, even if weather conditions do not warrant it, or they over-irrigate, as they know they will be restricted in future days. Hence, the efficacy of irrigation restrictions depends on local circumstances. There is no one universal rule of thumb. Below, however, is a list of observations gleaned from reviewing the literature:

- Enforcement
  Water savings will increase with enforcement of the restrictions. Voluntary irrigation restrictions prove less effective than mandatory restrictions. Enforcements through written warnings, financial penalties, and termination of water service improve restriction compliance. Effective communication and education can improve compliance and make enforcement easier. This conclusion is supported by the studies of Corpus Christi and Denver Metropolitan Area.

- Restriction Severity
  Water savings increase with more severe irrigation restrictions. Going from three to two to one-day-per-week irrigation, or once in 10 days, leads to greater water savings. The utilities reviewed universally used limiting irrigation to the morning and evening hours, when evapotranspiration is lower. This conclusion is supported by the studies of Corpus Christi, Southwest Florida Water Management District, Denver Metropolitan Area, and Florida Water Rates Evaluation of Single-Family Homes.

- Magnitude of Irrigation
  Water savings will be higher with water utilities that associate a relatively higher portion of their total potable water use with irrigation. Utilities with large commercial and industrial customer bases will not be as impacted. Utilities with customers who irrigate from alternative sources, such as reclaimed wastewater, shallow irrigation wells, or surface water, will not see as pronounced changes in their potable water use. This conclusion is supported by the studies of Southwest Florida Water Management District, Denver Metropolitan Area, and Florida Water Rates Evaluation of Single-Family Homes.

- Good Will
  Water savings from irrigation restrictions will be higher with customers who understand and perceive the need for restrictions to assist their water suppliers through times of water shortages. This conclusion is supported by the studies of Austin, Southwest Florida Water Management District, Denver Metropolitan Area, and Florida Water Rates Evaluation of Single-Family Homes.

- Water System Peaking
  Water managers must carefully anticipate and adjust restrictions to limit water-use peaks that are exacerbated by day-of-week and time-of-day irrigation restrictions. Forcing all irrigation to occur within limited windows of time can stress the water system, leading to loss in water pressure and compromising fire-suppression abilities. This conclusion is

supported by the studies of Fort Collins, and Southern Duval and Northwest St. Johns Counties.

- Evaluation of Water Savings
  All studies that evaluated the water savings associated with irrigation restrictions controlled for weather. Ignoring weather can severely bias the results, as demonstrated in the Fort Collins example. Researchers must also control for customer growth and the increasing use of alternative water-supply sources in isolating the impact from restrictions.

4.2. Conclusions from Empirical Evaluation

Our empirical analysis of water-use data supports the conclusion that the water savings that result from irrigation restrictions vary significantly with utility circumstances.

The irrigation-restriction water savings associated with Ocoee and Seminole County are convincing. Both utilities have relatively high levels of outdoor water use.

Based on analysis of 6,332 single-family homes in Ocoee, the average decline in water use was 11.6–12.8% after implementation of irrigation restrictions from 2001 to 2003. The savings were weather normalized and include only homes that existed before 1998 and had a continuous water-use history over 1998 to 2003. The savings do not appear to have declined over time but are persistent. Water rates and other factors were constant over the study period, leading us to conclude that the water reductions were caused by the water restrictions.

The Ocoee results generated by analysis of billing data were supported by analysis of daily water-production data. After irrigation restrictions were implemented, water use significantly decreased on Monday, Tuesday, and Friday—days when irrigation was prohibited. Water use, in contrast, increased on Wednesday, Thursday, Saturday, and Sunday—days when irrigation was allowed. Hence, it is clear that irrigation restrictions drove the water-use reductions measured with the billing data. Ocoee is the only utility where we analyzed both billing and water-production data.

In Seminole County, we analyzed the water use of irrigation meters associated with 2,715 homes—the same owners occupied the homes over the entire study period 1998 to 2003. The weather-adjusted water savings during 2001–2003 averaged 16.9–18.5%. These savings were based on water used only for irrigation, not total water use (including indoor uses). When put in a total home-water-use perspective, the savings were similar to those calculated for Ocoee. The water savings did not diminish over time, leading us to conclude that water savings are persistent over time. Water rates and other factors were constant over the study period, leading us to conclude that the water reductions were caused by the water restrictions.

Our analysis of daily water production at six other utilities generated mixed and perhaps misleading results, if water-use changes are exclusively ascribed to irrigation restrictions. Over our study period, these utilities experienced large increases in population, ranging from 8% to 36%. Although we adjusted for growth by dividing total water production by total estimated population to put water use on a per capita basis, there were still difficulties. The relative proportions between commercial and residential customers, for example, were not always constant over time. An examination of Apopka, for example, showed that commercial customers grew much faster than residential customers over our study period. This can bias our observation of per capita water use over time. In addition, new customers may have different water-use consumption from old customers—differences in water-fixture efficiency (e.g., toilets and showerheads) and landscape areas, plant materials, and irrigation systems challenge the assumption that the per capita water use of new customers should be the same as old customers. Further, all of the utilities studied are expanding wastewater reclamation to serve as a source substitute to potable water supplies. Because water-production data of potable supplies are impacted by such substitution, this also complicates the situation. All of these phenomena tend to warp daily per capita observations over time in unpredictable ways.

Hence, it is our conclusion that we cannot generally rely on daily water-production records to accurately estimate the water-use change associated with irrigation restrictions. Daily water-production records, however, can be valuable in detecting and quantifying changes in the day-of-week water-use pattern. If irrigation restrictions are effective, then we will see a drop in water use during non-irrigation days and an increase on designated irrigation days. Detecting relative day-of-week changes is not materially impacted by the customer growth, reclaimed wastewater, or other complicating factors.

Our analysis shows that the day-of-week patterns changed in concert with the irrigation restrictions at OCU and Winter Park. Water use showed a strong relative increase on Sunday, Wednesday, Thursday, and Saturday—the days when irrigation was allowed. Water use dropped sharply on Monday, Tuesday, and Friday, when irrigation was prohibited. The conflicting finding with OCU is that no annualized water savings were associated with the strong change in the day-of-week pattern. Apparently, customers were complying with the irrigation restrictions, but they were not generating water savings. We believe it more likely, however, that the 36% increase in population between 1997 and 2004 has altered per capita water use in unexpected ways. If new homes had relatively more water use, this could easily mask any irrigation-restriction water savings.

Winter Park, in contrast, experienced only an 8% increase in population over the study period. This stability gives us more confidence in predicting water savings from water-production data. The calculated savings are 15%, modestly higher than water-use billing results from Ocoee and Seminole County.

The results for Apopka are indeterminate. Regarding the day-of-week pattern, the odd-number street addresses showed the expected Wednesday and Saturday water-use increases. For the even-number street addresses, water use did not relatively increase. We are unsure of the cause. The total water-use reduction associated with the post-restriction period is 11%. We observed, however, that reclaimed wastewater use had progressively grown to a significant extent over the study period. We also note that water rates increased significantly, by 64%, in inflation-adjusted dollars, for water use over 15 thousand gallons per month.

DeLand experienced its largest relative drop in water use on Monday and Tuesday, as expected, but not on Friday. Water use relatively increased on Saturday and Sunday. Water use on Wednesday and Thursday was less than we expected. The total water-use reduction, post-restrictions, is 11%. Because customer growth between 1997 and 2004 was a modest 12% and water rates have been stable, we believe this tends to support water savings in the range of Winter Park, Ocoee, and Seminole County.

Sanford showed some evidence of a response to irrigation restrictions, but results were mixed. Water use dropped on Tuesday and to a lesser degree on Friday but not Monday. Hence, the day-of-week change was minimal. We note that Sanford has less potable water used for irrigation, as expressed by the modest seasonal variation in water use. The water savings in the post-restriction period were 3%. The population change from 1997 to 2004 was 24%—again, this could significantly distort results.

Port Orange showed no change in the day-of-week water-use pattern. This is as expected, as potable water from the utility for irrigation was minimal, and no water savings from the irrigation restrictions were observed.

4.3. Future Research

There is much merit in researchers evaluating both daily water production and monthly water billing data for the same utility. Both sources of data provide a different angle, adding to our understanding of irrigation-restriction impacts. We were only able to do this for Ocoee in this study. Future studies should expand upon this to learn more about the impacts caused by irrigation restrictions.

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APPENDIX A. SJRWMD WATER SHORTAGE ORDER DOCUMENTS

This appendix includes:

- January 10, 2001, District news release
- January 16, 2001, letter from District to permit-holders, announcing the irrigation restrictions
- May 16, 2002, District brochure

The 11-page District order that details the irrigation restrictions can be obtained from the District and is titled the "Fourth Amended Order Declaring a Severe Water Shortage within Lake, Marion, Orange, Polk, Seminole, and Volusia Counties.