MUNICIPAL WATER DISTRICT OF ORANGE COUNTY

2008 Urban Drought Assistance Grant

Water Budget Evaluation Study
Five Year Monitoring Report / June 12, 2020

MWDOC

RAFTELIS

June 12, 2020

Mr. Karl Seckel, P.E.
Assistant General Manager
Municipal Water District of Orange County
PO Box 20895
Fountain Valley CA 92728

Subject: Water Budget Evaluation Study Report

Dear Mr. Seckel,

Raftelis is pleased to provide this Water Budget Evaluation Study Five Year Monitoring Report to the Municipal Water District of Orange County (MWDOC), which fulfils the five-year reporting requirement of the agency's 2008 Urban Drought Assistance Grant agreement with the California Department of Water Resources (DWR). This report summarizes the background, methods, and key findings of the study.

The major objectives of the study include the following:

1. Develop a methodology for evaluating the impacts of budget based tiered rates (BBTRs) on household water consumption in Orange County.
2. Estimate the savings in water consumption over a five-year period that are attributable to BBTRs, for the agencies which adopted BBTRs under the grant agreement.
3. Identify avenues for further research on the effects of BBTRs and other drivers of water consumption.

It has been a pleasure working with you, and we thank you and the MWDOC staff for the support provided during the course of this study. We also acknowledge Monobina Mukherjee and Drew Atwater of Moulton Niguel Water District for their help with the modeling effort and coding which went into the study.

Sincerely,

Raftelis

Sanjay Gaur
Vice President

Karter Harmon
Consultant

445 S Figueroa Street, Suite 1925
Los Angeles, CA 90071
www.raftelis.com

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1. Executive Summary

1.1. Study Overview

In recent years, interest in budget based tiered rates (BBTRs, also referred to as water budgets) has grown across California in response to recurrent droughts, other threats to water supply, and calls for increased water use efficiency and conservation. In 2008, the California Department of Water Resources (DWR) selected MWDOC for an Urban Drought Assistance Grant and corresponding study. This grant began in May 2009. Over the course of the grant period, MWDOC's member agencies were invited to evaluate water budget rate structures, conduct mapping studies, develop water budgets for their service areas, and consider converting to BBTRs. For agencies which adopted BBTRs, the grant requires MWDOC to conduct five-year monitoring of water savings attributable to the new rate structure.

The primary objective of this study is to estimate savings in household water consumption which can be attributed to adoption of BBTRs by member agencies of the Municipal Water District of Orange County (MWDOC) which converted to BBTRs under the DWR grant study. These agencies include East Orange County Water District (EOCWD), El Toro Water District (ETWD), and Moulton Niguel Water District (MNWD). This study fulfills the five-year monitoring requirement under the DWR grant, while providing insight on how BBTRs can affect household water usage independent of other factors.

1.2. Approach and Methodology

To evaluate water savings over the five-year period following BBTR adoption by MNWD and ETWD, and adoption of water budget allocation information for customers by EOCWD, we adopted an approach based on past studies by researchers at the University of California, Riverside. We developed our estimates of savings attributable to BBTRs using a three-step approach:

1. Step 1: Develop a model of water demand at the household level, for the time period before BBTRs were adopted.
2. Step 2: Use this model to predict what usage would have been under the prior rate structure.
3. Step 3: Compare these predictions to the actual water usage under BBTRs to calculate savings.

We estimated demand models using multivariate ordinary least squares (OLS) regression with fixed effects. Our models included several variables thought to influence household water demand. These include the average price of water, reference evapotranspiration (ETo), season, and the presence of drought-related landscape watering restrictions. We estimated savings for all households in each agency which used water in every bill period over the study timeline from November 2007 through December 2016. We also estimated truncated models for three user groups (i.e., low, medium, and high volume users), defined based on average usage per bill period, to evaluate how BBTRs influence consumption for customers using different amounts of water.

1.3. Results and Discussion

The table below summarizes the water savings for all three agencies, for all users together and for low, medium, and high volume users separately. We calculated savings based on the difference in predicted and actual usage during the period following BBTR adoption (or, in the case of EOCWD, assignment of water budget allocation information to customers). We also calculate savings for the time period following April 2015, when state mandated conservation measures were put in place in response to the recent drought.

In the table below, Accounts (Total) indicates the number of unique households in our dataset. Savings (Total) indicates the total savings in water usage, in hundred cubic feet (CCF) over the entire time period since BBTR adoption. Drought savings (Total) indicates the savings during the period following the implementation of state-mandated conservation measures. Low, Med, and Hi refer to the results of stratified models for each user class, separated based on the average volume of water usage in each bill period. For example, MNWD had 14,828 households in their dataset which continuously used water in every bill period from November 2007 through December 2016. Our model indicates that converting to BBTRs saved 1,409,080 CCF of water overall. This reflects a savings of 9.1% under the usage that we predict would have occurred under the prior rate structure. From April 2015 through December 2016, we estimate that water usage was 690,761 CCF, or 15.3%, lower than it would have been under the prior rate structure.

Table 1. Summary of Savings for All Agencies

	EOCWD	ETWD	MNWD
Accounts (Total)	695	3497	14828
Savings (Total)	43955	128533	1409080
Savings (Total%)	3.4%	3.5%	9.1%
Drought Savings (Total)	85141	128717	690761
Drought Savings (Total%)	6.5%	3.5%	15.3%
Accounts (Low)	232	1166	4943
Savings (Low)	-1595	29789	502313
Savings (Low%)	-0.9%	3.9%	19.0%
Drought Savings (Low)	8430	26342	38111
Drought Savings (Low%)	16.9%	14.5%	6.0%
Accounts (Med)	232	1166	4943
Savings (Med)	8005	47288	217363
Savings (Med%)	2.2%	4.0%	5.1%
Drought Savings (Med)	21005	42470	206935
Drought Savings (Med%)	20.9%	15.0%	15.9%
Accounts (Hi)	231	1165	4942
Savings (Hi)	62153	70923	785982
Savings (Hi%)	8.0%	4.0%	9.1%
Drought Savings (Hi)	61721	65253	543483
Drought Savings (Hi%)	29.0%	15.9%	20.2%

All models were statistically significant, and had moderate to high explanatory power, with between 44% and 81% of the total variation in household water consumption accounted for by each model. Our analysis indicates modest savings in household water consumption attributable to BBTRs among the three agencies. Savings were realized for agencies which converted to a budget based rate structure, as well as under EOCWD's information-only approach. Savings appear generally higher for medium and high-volume users than for low-volume users.

Our models fit the data fairly well and control for all factors thought to influence water usage for which we have data. However, the impact of the recent drought on water consumption was unprecedented, presenting a significant obstacle to accurately measuring savings due to rate structure over this time period. Although we include a variable for conservation restrictions in our model, the restrictions in our pre-rate change dataset are related to the 2011-2013 drought, which was relatively mild compared to the drought conditions from 2014-2016. Therefore, it is likely that this variable does not capture the full effect of the severe drought and associated mandated restrictions. Further research into the effect of the recent drought, including both the drought itself and the state-mandated water use reductions, may help to decouple the effects of the drought from those of rate structures in Orange County. This area of research may also help to identify what characteristics of water budgets are most effective at mitigating the water supply volatility associated with drought events. With ongoing climate change increasing the chances of more severe droughts in the future, insights from this research will be invaluable to water agencies and their customers, whether under water budgets or traditional rate structures.

2. Introduction

This section of the report discusses and provides the necessary context and background information on BBTRs, MWDOC's Urban Water Assistance Grant with DWR, and the background and objectives of this study.

2.1. Agency Background

The Municipal Water District of Orange County (MWDOC) is a planning, resource management, emergency preparedness, and communication wholesale agency in Orange County, a member agency of the Metropolitan Water District of Southern California (MWD), and the imported water wholesaler to 28 retail agencies (member agencies) in Orange County, California. MWDOC's primary mission is to be an active member of MWD and to provide regional water management and planning for its service area. Key focus areas are water supply and reliability planning, facilitation for development of supply projects, water use efficiency implementation on a regional basis, support of water recycling projects/programs, public information, legislative advocacy, water education, and emergency preparedness.

Orange County is home to 3.1 million people, and a 1.56 million person work force that produces $298 billion in gross domestic product annually. A reliable source of water is critical to maintaining the local economy. Orange County's climate is a classic dry Mediterranean climate with a warmer gradient from the coast to the inland mountains; average annual precipitation in Santa Ana is slightly less than 14 inches per year. The potential evapotranspiration (ETo) averages around 50 inches per year, varying with location and is about four times the annual average precipitation, which predominantly occurs over three "winter" months of the year. The natural warm and dry climate and the large variance in annual and seasonal rainfall make managing water supplies an ongoing challenge for MWDOC and its member agencies.

Local water supplies in Orange County include a mix of surface water, groundwater, and recycled water. The north Orange County area has a large groundwater basin that is managed by the Orange County Water District (OCWD). Other local sources of groundwater beyond those provided by OCWD are found in various parts of the County, but are much smaller in volume and annual yield. On average, local sources supply slightly more than half of the consumptive use of water in the county. Imported water from MWD provides the remaining water supplies in Orange County.

2.2. Study Background

2.2.1. BUDGET BASED TIERED RATES

Budget Based Tiered Rates (BBTRs), also known as "water budgets," constitute a method of assessing water rates based on the specific demands of individual water users. Unlike traditional water rate structures wherein users are billed at either a uniform rate or specific rate tiers common to all users, BBTRs employ a scientific and policy-based methodology to determine a reasonable amount of water needed for each water user within a water system for indoor and outdoor usage. Developing water budgets within an agency provides customers with valuable information on a reasonable amount of usage for their household, as well as their usage trends. Rates based on water budgets send a price signal to water users that is directly tied to their usage efficiency, as tiers based on water budgets generally increase in cost as users approach or exceed their budgeted allotment.

Southern California's interest in BBTRs has grown over the past several years especially due to recurring climatological droughts and Endangered Species Act (ESA) events leading to increasing volatility in water supply. The Colorado River basin has been in a continuing drought since 2000, while the State Water Project has also been in a hydrologic drought and under increasingly stringent regulatory reductions on Delta exports. In 2008, the governor proclaimed a statewide drought that lasted through 2010. Based on the water supply shortages and Statewide restrictions, MWD imposed mandatory water rationing in 2009 and 2010. The California State Legislature responded with regulations that require a mandatory 20 percent reduction in per capita water use by 2020.

A severe drought that began in 2012 led the governor to declare another drought emergency, calling for a 20 percent reduction in demand to respond to the limited supplies in the State relative to water use in 2013. In followup, the State Water Resources Control Board (SWRCB) took emergency action in July 2014 prohibiting water wasting practices and requiring all retail water providers to either move to the stage of its water shortage contingency plan that imposes mandatory restrictions for outdoor irrigation or submit an "Alternate Plan" demonstrating a superior level of savings from BBTRs or other conservation measures to the State Board for approval. In April 2015, the governor ordered mandatory water usage reductions across the state in response to the ongoing drought. This unprecedented drought continued into late 2016, and the state of emergency was not lifted until April 2017.

Due to the continuing recurrence and seemingly increasingly severe droughts, along with state and local water use restrictions, a growing number of water providers have used or are considering the use of BBTRs as an effective and equitable way to achieve reductions in water demands while seeking stable revenue generation and customer acceptance. One 2015 review describes BBTRs as "a practice that allows water utilities to obtain a high level of conservation without jeopardizing the financial and political stability of the water utility" (Dinar & Ash 2015). A 2016 study by Mukherjee et al. found that the urgency of decreasing water demand in California requires effective pricing mechanisms, and cited MNWD as an example of an agency which has effectively established conservation based water rates while complying with Proposition 218 requirements (Mukherjee et al. 2016). A 2019 study by the Environmental Finance Center at the University of North Carolina at Chapel Hill found that rate structures adopted by California water agencies during the recent drought influenced price signals, and that both rates themselves and elements of the rate structure were necessary to create price signals that incentivize conservation (Hughes et al. 2019). This study also found that water systems that started with a higher level of per-capita water use were able to achieve greater savings than water systems with more efficient customers.

Other studies focused specifically on Orange County water agencies (Baerenklau et al. 2014; Schwabe & Baerenklau 2016) have found significant savings associated with both inclining block rate structures and BBTRs relative to uniform rate structures, as discussed in Section 3 of this report.

2.2.2. DWR GRANT

In May 2008, the Orange County Grand Jury recommended that each retail water provider in Orange County consider a BBTR structure. Also in 2008, the California Department of Water Resources (DWR) selected MWDOC and a number of its member agencies for an Urban Drought Assistance Grant and corresponding study. This grant began in May 2009. Over the course of the grant period, MWDOC's member agencies were invited to conduct mapping studies, develop water budgets for their service areas, and consider converting to BBTRs.

In 2015, MWDOC submitted a report to DWR detailing the key issues and findings of the grant study. From 2009 to 2015, two member agencies participating in the grant study converted their rate structures to BBTRs, and one developed individualized water budgets for informational purposes to share with their customers how efficiently they were using water and to fairly allocate water in the event of a shortage. The 2015 report found that all three water providers reported positive customer response, increased conservation funding and generally more stable revenues as a result of BBTR adoption. Agencies which did not convert to BBTRs generally cited philosophical opposition to budget-based rates, or prohibitive costs associated with upgrading billing systems to accommodate a more complex rate structure. As the potential for increased water usage efficiency is a key theoretical benefit of BBTRs, the grant requires a follow-up study to address the five-year impact of BBTR adoption on water usage.

2.3. Five Year Follow-up Study Objectives

In 2017, MWDOC convened a meeting with Raftelis and three member agencies which adopted water budgets and BBTRs as part of the grant, to discuss options for fulfilling the five-year evaluation requirement. The agencies participating in five-year monitoring include East Orange County Water District (EOCWD), El Toro Water District (ETWD), and Moulton Niguel Water District (MNWD).

The primary objective of this study is to estimate savings which can be attributed to BBTR adoption for the MWDOC member agencies which converted to BBTRs under the DWR grant study. This fulfils a five-year monitoring requirement under the grant, while providing insight on how BBTRs can affect household water usage independent of other factors. While not a primary focus, this study also identifies avenues for further research which may shed light on outstanding questions and nuances surrounding BBTRs and their impact on water usage.

3. Approach and Methodology

3.1. Methodological Background

Past studies have estimated savings in water consumption associated with various rate structures in Orange County. The two studies which primarily informed the basis for the modeling approach in this study were both conducted by researchers at the University of California, Riverside (UCR). A 2014 study (Baerenklau et al. 2014) investigated the impact of a fiscally-neutral increasing block rate structure on water demand for Eastern Municipal Water District (EMWD). This study evaluated several different methods and model specifications for estimating water savings, and ultimately selected an ordinary least squares (OLS) model of water usage at the household level. This study found an 18 percent reduction in water use associated with adopting increasing block rates.

A 2016 study (Schwabe & Baerenklau 2016) applied a discrete-continuous choice (DCC) model to estimate savings associated with BBTR adoption by MNWD. This study found a temporary "peak shaving" effect of BBTR adoption, during a period of unusually high ETo when predicted water use was particularly high. In both the 2014 and 2016 studies, savings were estimated by first calculating a "pre-rate change" model of water consumption at the household level, controlling for all factors thought to influence water demand, and then using this model to predict what usage would have occurred post-rate change had the existing (i.e., "traditional") rate structure remained in place. Variables in the 2016 study included the average consumption price of water (independent of any fixed charges, fees, or capital improvement surcharges), reference evapotranspiration (ETo, which serves as a proxy for vegetative water demand given precipitation), a dummy variable for the presence or absence of landscape watering restrictions, seasonal fixed effects, and household income. The 2016 study also included fixed effects for each household to control for unobserved heterogeneity between households (which could include factors such as household size, age of residents, plot size, and other factors).

3.2. Modeling Approach

To evaluate water savings over the five-year period following BBTR adoption by MNWD and ETWD, and adoption of water budget information for customers by EOCWD, we adopt an approach based on both the 2014 and 2016 UCR studies. Based on preliminary model evaluations and discussions with MWDOC and the participating agencies, we resolved to apply the OLS methodology of the 2014 UCR-EMWD study, using a similar set of variables as the 2016 UCR-MNWD study. We found this approach both computationally efficient and satisfactory at fitting the provided data for all three agencies.

We develop our estimates of savings attributable to BBTRs using a three-step approach:

1. Step 1: Develop a model of water usage at the household level, for the time period <u>before</u> BBTR was adopted.
2. Step 2: Use this model to predict what usage would have been under a traditional rate structure.
3. Step 3: Compare these predictions to the actual water usage under BBTRs to calculate savings.

The general specification for our household demand models is as follows:

$$ln(w_{it}) = \theta ln(p_{it}) + \boldsymbol{\beta} z_t + \boldsymbol{\omega} h_i + \varepsilon_{it}$$

where w_{it} is the water demand by household *i* in billing period *t*; p_{it} is the average price of water paid by household *i* in billing period *t*, z_t is a vector of explanatory variables, h_i is a vector of fixed effects accounting for individual household heterogeneity, and ε_{it} is an error term. θ, $\boldsymbol{\beta}$, and $\boldsymbol{\omega}$ represent parameters to be estimated ($\boldsymbol{\beta}$ and $\boldsymbol{\omega}$ are vectors of parameters for explanatory variables and household fixed effects, respectively).

Our demand models include the following variables:

- ***Water consumption (w_{it}):*** The amount of water consumed (in CCF) by each household in each time period. This is the dependent variable in our analysis.
- ***Price of water (p_{it}):*** The average price per CCF paid for water by each household in each time period, not including the monthly fixed charges.
- ***Reference evapotranspiration (ETo):*** This accounts for weather variability and landscape water demands in each time period.
- ***Conservation restrictions:*** This is a dummy variable for the presence of mandatory or advised landscape watering restrictions.
- ***Fall:*** This is a dummy variable denoting the months September through November.
- ***Spring:*** This is a dummy variable denoting the months March through May.
- ***Summer:*** This is a dummy variable denoting the months June through August.
- ***Household characteristics (h_i):*** This is a large set of dummy variables, one for each household, to capture time-invariant heterogeneity between individual water users.

By controlling for all identifiable factors thought to influence water demand, we identify the changes in water use over the study period that may be attributable to BBTR adoption.

Our set of explanatory variables differs from the 2016 UCR study in two ways. First, we do not include the household income variable, due to lack of data on household income for some agencies. This variable was found to be statistically insignificant and of low effect size in the 20 16 UCR study. We also note that, to the extent that household income does not change much within households across time, its effect will be captured as part of the fixed effects for each individual household. Secondly, the 2016 UCR study included a "Time Trend" variable, which is a discrete variable accounting for changes in water consumption from year to year. While this variable greatly improved model fit in the case of MNWD, it decreased goodness of fit for the other two agencies, likely due to overfitting. Therefore we do not include a time trend in our models for EOCWD or ETWD.

We estimate four models of water demand for each agency. The first model includes the full dataset for each agency. We also calculate one model for each of three user groups defined based on water usage (i.e., low, medium, and high volume users). These user groups are defined based on tertiles (i.e., three groups of equal size) of average water consumption per bill period over the dataset.

Using these models of water demand, we calculate a predicted usage curve for the time period following BBTR adoption, and take the difference of this prediction and the observed usage to estimate savings. We report savings both for the entire time period following the rate change, and for the period following state-mandated drought restrictions beginning in April 2015.

3.3. Data Summary

Below are summary statistics for the three agencies included in the study, summarized by year. Data are for each household individual household in each bill period. Note that our study includes only continuous households (i.e., only households with bills and corresponding data in every bill period over the study period). This eliminates any potential bias which may be introduced by households beginning water service after the rate change, or exiting the study before the end of the five-year monitoring period. Our dataset spans from November 2007 through December 2016, which provides more than 5 years of data post-rate change for all three agencies.

Usage (i.e., household consumption per bill period) is in hundred cubic feet (CCF); average rate is in dollars per CCF of consumption.

Table 2. Summary of Key Variables for EOCWD

Year	Usage	Average Rate	ETo	# Households	BBTR
2007	64.3	$1.53	2.15	695	No
2008	67.8	$1.53	4.35	695	No
2009	63.5	$1.75	4.17	695	No
2010	55.2	$2.00	3.86	695	No
2011	55.2	$2.08	4.12	695	After June
2012	59.6	$2.19	4.28	695	Yes
2013	59.9	$2.39	4.45	695	yes
2014	61.2	$2.48	4.47	695	Yes
2015	43.6	$2.48	4.43	695	Yes
2016	43.8	$2.48	4.80	695	Yes

Note that EOCWD converted to BBTRs in June 2011. EOCWD bills bimonthly, so data are for two-month periods.

Table 3. Summary of Key Variables for ETWD

Year	Usage	Average Rate	ETo	# Households	BBTR
2007	15.7	$1.41	2.20	3,497	No
2008	17.8	$1.43	4.20	3,497	No
2009	16.2	$1.60	4.43	3,497	No
2010	14.3	$1.86	4.08	3,497	After August
2011	14.0	$1.98	4.12	3,497	Yes
2012	14.5	$2.07	4.33	3,497	Yes
2013	14.6	$2.16	4.42	3,497	Yes
2014	14.3	$2.21	4.60	3,497	Yes
2015	11.8	$2.23	4.39	3,497	Yes
2016	11.1	$2.29	4.21	3,497	Yes

Note that ETWD converted to BBTRs in August 2010. ETWD bills monthly, so data are for one-month periods.

Table 4. Summary of Key Variables for MNWD

Year	Usage	Average Rate	ETo	# Households	BBTR
2007	17.9	$1.55	2.63	14,828	No
2008	18.6	$1.55	4.00	14,828	No
2009	16.9	$1.67	4.20	14,828	No
2010	15.0	$1.93	3.85	14,828	No
2011	15.1	$2.18	4.14	14,828	After June
2012	15.5	$2.26	4.64	14,828	Yes
2013	15.7	$2.27	4.23	14,828	yes
2014	15.7	$2.26	4.29	14,828	Yes
2015	12.8	$2.56	4.30	14,828	Yes
2016	12.7	$2.86	3.78	14,828	Yes

Note that MNWD converted to BBTRs in June 2011. MNWD bills monthly, so data are for one-month periods.

4. Results

This section includes a side-by-side summary of estimated savings for all three agencies. We report savings both for the entire time period following the rate change, and for the period following state-mandated drought restrictions beginning in April 2015. See the Appendix for more detailed results, including regression coefficients for key variables and figures displaying predicted and actual water usage for each user group in each agency.

4.1. Summary of Results

Table 4 below shows the estimated savings in water consumption that are attributed to adoption of BBTRs in our study. In the table below, Accounts (Total) indicates the number of unique households in our dataset. Savings (Total) indicates the total savings in water usage, in hundred cubic feet (CCF) over the entire time period since BBTR adoption. Drought savings (Total) indicates the savings during the period following the implementation of state-mandated conservation measures. Low, Med, and Hi refer to the results of stratified models for each user class, separated based on the average water usage in each bill period. For example, MNWD had 14,828 households in their dataset which continuously used water in every bill period from November 2007 through December 2016. Our model indicates that converting to BBTRs saved 1,409,080 CCF of water overall. This reflects a savings of 9.1% under the usage that we predict would have occurred under the prior rate structure. From April 2015 through December 2016, we estimate that water usage was 690,761 CCF, or 15.3%, lower than it would have been under the prior rate structure.

Table 5. Summary of Savings for All Agencies

	EOCWD	ETWD	MNWD
Accounts (Total)	695	3497	14828
Savings (Total)	43955	128533	1409080
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Drought Savings (Hi)	61721	65253	543483
Drought Savings (Hi%)	29.0%	15.9%	20.2%

All models were statistically significant, and had moderate to high explanatory power, with between 44% and 81% of the total variation in household water consumption accounted for by each model (see the Appendix for more detail on regression results). Coefficients on price were negative as anticipated. A 1% increase in water price was associated with a decrease in water demand of 0.26% for EOCWD, 0.4% for ETWD, and 2.4% for MNWD. Overall, our analysis indicates that BBTR adoption was associated with overall reductions in water use of between 3.4% and 9.1%, independent of other factors. The estimated overall effect of the rate structure on water usage in MWND (9.1%) comports with the estimated savings of between 5% and 15% reported in the 2016 UCR-MNWD study (Schwabe & Baerenklau 2016).

5. Conclusion

5.1. Discussion

This analysis indicates modest savings in household water consumption attributable to BBTRs among the three agencies participating in the five-year monitoring study. Savings were realized for agencies which converted to a budget based rate structure, as well as under EOCWD's information-only approach. This implies that simply communicating information to households about their water usage and efficiency relative to a reasonable, science-based budgeted allocation can result in savings. However, we note that the highest savings in our study were realized by MNWD, which implemented a full rate change. Our comparison of predicted and actual water usage for MNWD following the rate change (see Appendix) suggests a sort of near-term "peak shaving," consistent with the results of the 2016 UCR study. However, this pattern contrasts with the comparisons for EOCWD and ETWD, both of which appear not to have realized significant savings until later in the time period when the recent drought was at its peak.

We note that savings for medium and high volume users were generally higher than savings for low volume users. This follows from the hypothesis that BBTRs may have the greatest benefit in terms of savings for customers using the greatest share of water. To the extent that medium and high volume users are the most inefficient in terms of exceeding their budgeted allotment, our analysis is consistent with past studies indicating greater savings for inefficient users. However, water use efficiency is not explicitly addressed in our partition of user groups, only the average consumption over the entire time period.

Our coefficients on the average rate variable (see Appendix) indicate that a 1% increase in water price is associated with a decrease in water demand of 0.3%, 0.4%, and 2.4% depending on the agency. MNWD customers had the highest price sensitivity, while EOCWD had the lowest. Note that while average price grew over time, it did not vary widely either within or between agencies. Differences in price sensitivity between agencies may be due to income related factors, a higher share of overall household expenditures on utilities, or other factors.

ETo had a small effect on average water demand in our analysis, with a 1-unit increase in ETo being associated with an approximately 0.08-0.10% decrease in demand. This suggests that water users in the participating agencies may be more sensitive to price than weather. However, we note that ETo was fairly stable across years in the pre-rate change time period than during the more severe drought years from 2012 onwards.

The impact of the recent drought on water consumption was unprecedented, and likely the greatest obstacle to accurately measuring savings due to rate structure over this time period. For example, our analysis indicates that the difference in observed and predicted water usage was significantly higher, in general, during the time period when mandatory drought restrictions were in place. This may be due to the effect of BBTRs in communicating information on water usage and incentivizing efficiency, or it may be that the drought itself and the widespread and consistent news coverage and communication from the State regarding penalties for water waste that depressed water usage independently of rate structure or the other explanatory factors in our models. Although we include a variable for conservation restrictions in our model, the restrictions in our pre-rate change dataset are related to the 2011-2013 drought, which was relatively mild compared to the drought conditions from 2014-2016. Therefore it is likely that this variable does not capture the full effect of the severe drought and associated restrictions. The unprecedented nature of this drought, and the interrelatedness of BBTRs to both weather and household water demand, makes it difficult to fully separate the effects of the drought from those of the rate changes.

5.2. Future Research

Future research may address a number of issues related to, but outside the scope of, this five-year monitoring study. The effectiveness of BBTRs in producing savings for users of differing levels of water use efficiency was examined in the 2016 UCR study. Further research in this area may provide insight to agencies as to whether BBTRs may be especially effective in reducing their water demands (e.g., if they have a particularly high proportion of inefficient users).

One possible explanation for the differences in savings between agencies in our study may be the level and type of outreach undertaken by agencies in support of water budgets, and differences in general water use efficiency. BBTRs not only encourage customers to use water more efficiently, they provide information to agencies about how to target conservation programs for optimal savings. Further research into the impacts of water budget information campaigns and specific types of outreach may help to highlight what steps agencies can take to make BBTRs more effective at reducing water consumption and improving efficiency.

Finally, further research into the effect of the recent drought, including both the drought itself and the state-mandated water use reductions, may help to decouple the effects of the drought from those of rate structures in Orange County. This area of research may also help to identify what characteristics of water budgets are most effective at mitigating the water supply volatility associated with drought events. With ongoing climate change increasing the chances of more severe droughts in the future, insights from this research will be invaluable to water agencies and their customers, whether under water budgets or traditional rate structures.

References

Baerenklau, K., Schwabe, K.A., and Ariel Dinar. 2014. Do Increasing Block Rate Water Budgets Reduce Residential Water Demand? A Case Study in Southern California. Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's 2014 AAEA Annual Meeting, Minneapolis, MN, July 27-29, 2014.

Dinar, A. and Tom Ash. 2015. Water Budget Rate Structure: Experiences from Several Urban Utilities in Southern California. *Use of Economic Instruments in Water Policy: Insights from International Experience.* Chapter 11. Global Issues in Water Policy, Volume 14. Lago, M., Mysiak, J., Gómez, C.M., Delacámara, G., and Alexandros Maziotis, Ed.

Hughes, J., Eskaf, S., and Liz Harvell. 2019. Pricing California's Water During the Drought: Can Rate Structures Provide an Incentive for Conservation? *Water Finance and Management*, February 2019.

Mukherjee, M., Mika, K., and Mark Gold. 2016. Overcoming the Challenges to Using Tiered Water Rates to Enhance Water Conservation. *California Journal of Politics and Policy,* 8(3).

Municipal Water District of Orange County. 2015. Final Report: Budget Based Tiered Rates in Orange County for Water Management and Droughts. Technical report to the California Department of Water Resources under 2008 Urban Drought Assistance Grant.

Schwabe, K., and Kenneth Baerenkau. 2016. Water Conservation Study – Phase 1 Summary Report. Technical Report to Moulton Niguel Water District.

Appendix

This appendix contains more detailed regression results for our models for each of the four agencies. Included here are adjusted R-squared values, as well as the coefficients for price, ETo, and the presence of conservation restrictions. We do not report effect sizes for seasonal or household fixed effects; however, we note that the seasonal fixed effects in our models had the expected coefficients relative to one another, with average water usage lowest in winter and highest in summer. Also included are figures depicting the predicted and actual usage in each model, as well as the 12-month moving averages of usage.

Table 6. Detailed Results for EOCWD

EOCWD			
Accounts (Total)	695		
Savings (Total)	43955	*Adj. R2*	0.790
Savings (Total%)	3.4%	*β (log Price)*	-0.275
Drought Savings (Total)	85141	*β (ETo)*	0.173
Drought Savings (Total%)	6.5%	*β (ConsRestrict)*	-0.031
Accounts (Low)	232		
Savings (Low)	-1595	*Adj. R2*	0.638
Savings (Low%)	-0.9%	*β (log Price)*	-0.334
Drought Savings (Low)	8430	*β (ETo)*	0.154
Drought Savings (Low%)	16.9%	*β (ConsRestrict)*	-0.009
Accounts (Med)	232		
Savings (Med)	8005	*Adj. R2*	0.498
Savings (Med%)	2.2%	*β (log Price)*	-0.310
Drought Savings (Med)	21005	*β (ETo)*	0.190
Drought Savings (Med%)	20.9%	*β (ConsRestrict)*	-0.036
Accounts (Hi)	231		
Savings (Hi)	62153	*Adj. R2*	0.637
Savings (Hi%)	8.0%	*β (log Price)*	-0.180
Drought Savings (Hi)	61721	*β (ETo)*	0.176
Drought Savings (Hi%)	29.0%	*β (ConsRestrict)*	-0.049

Figure 1. Results for EOCWD (All Users)

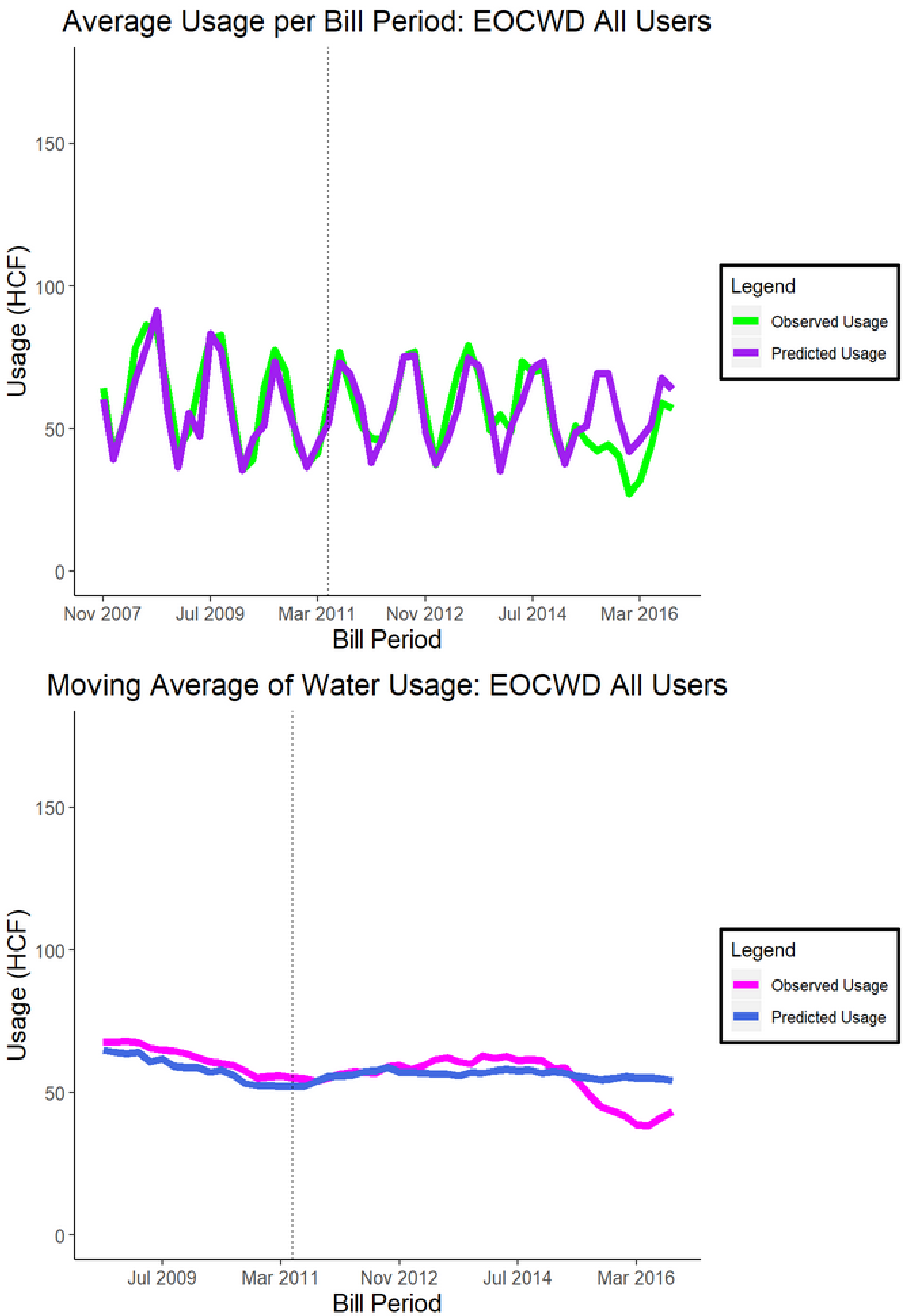
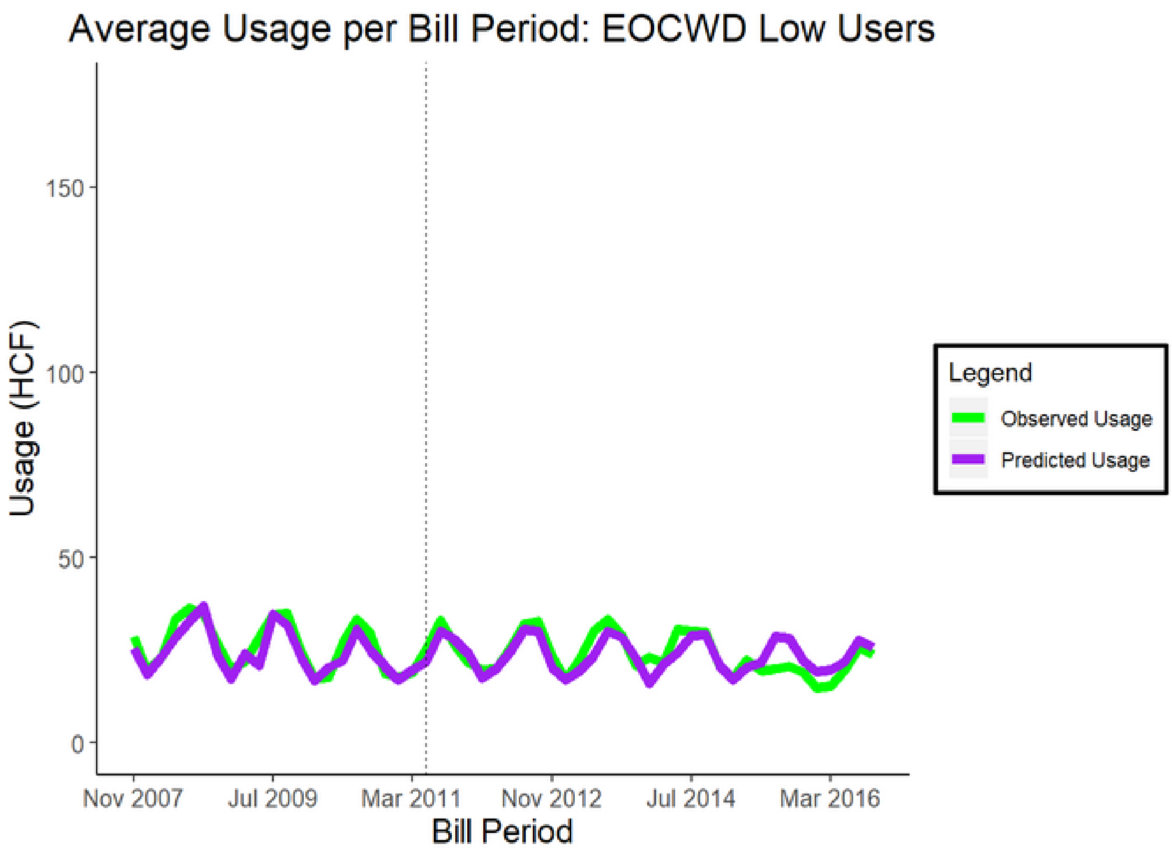


Figure 2. Results for EOCWD (Low-Volume Users)



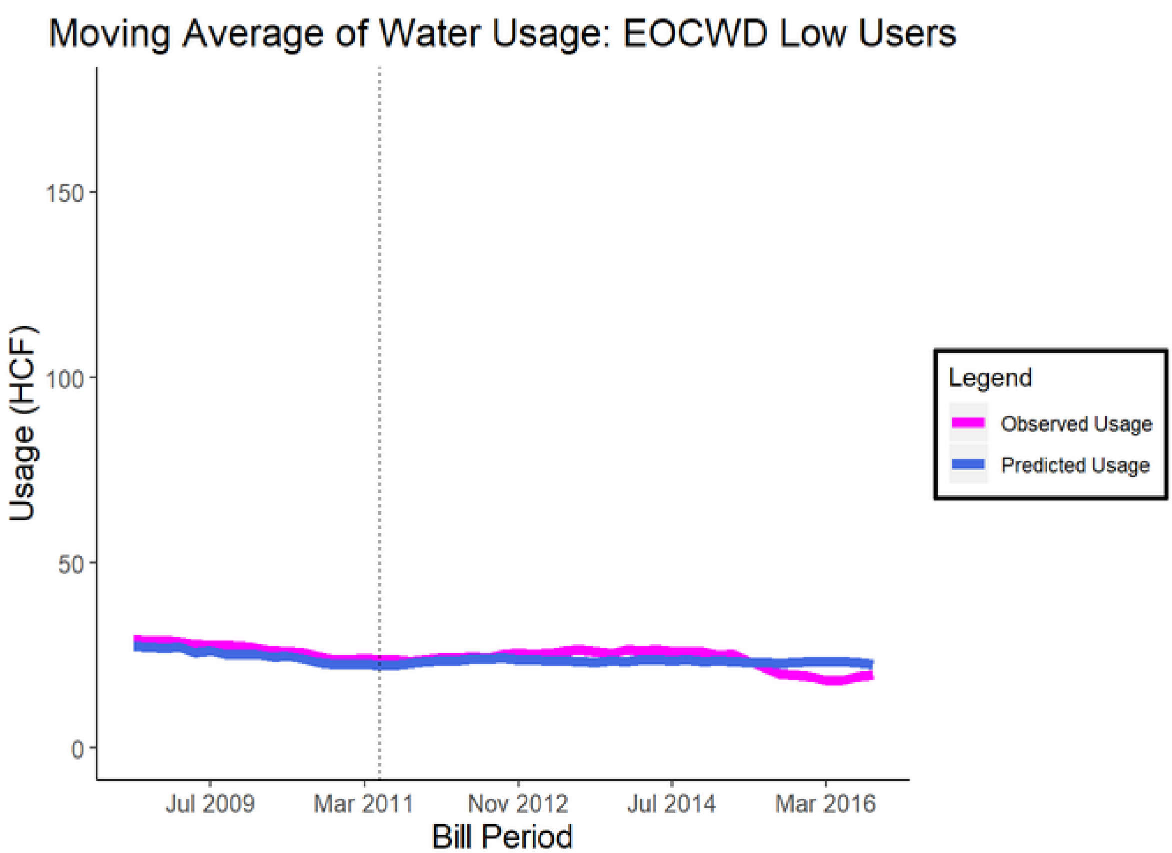


Figure 3. Results for EOCWD (Medium-Volume Users)

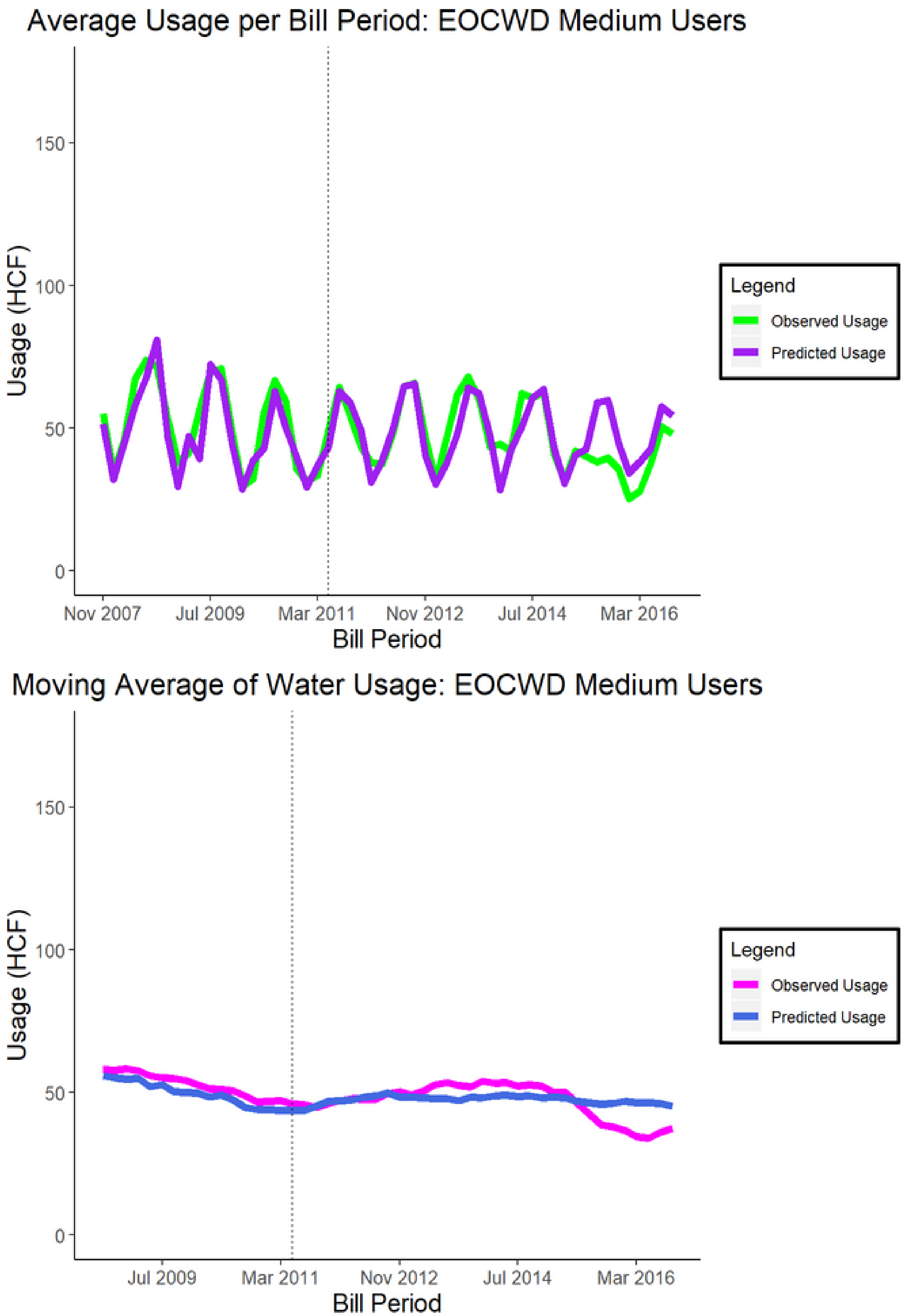


Figure 4. Results for EOCWD (High-Volume Users)

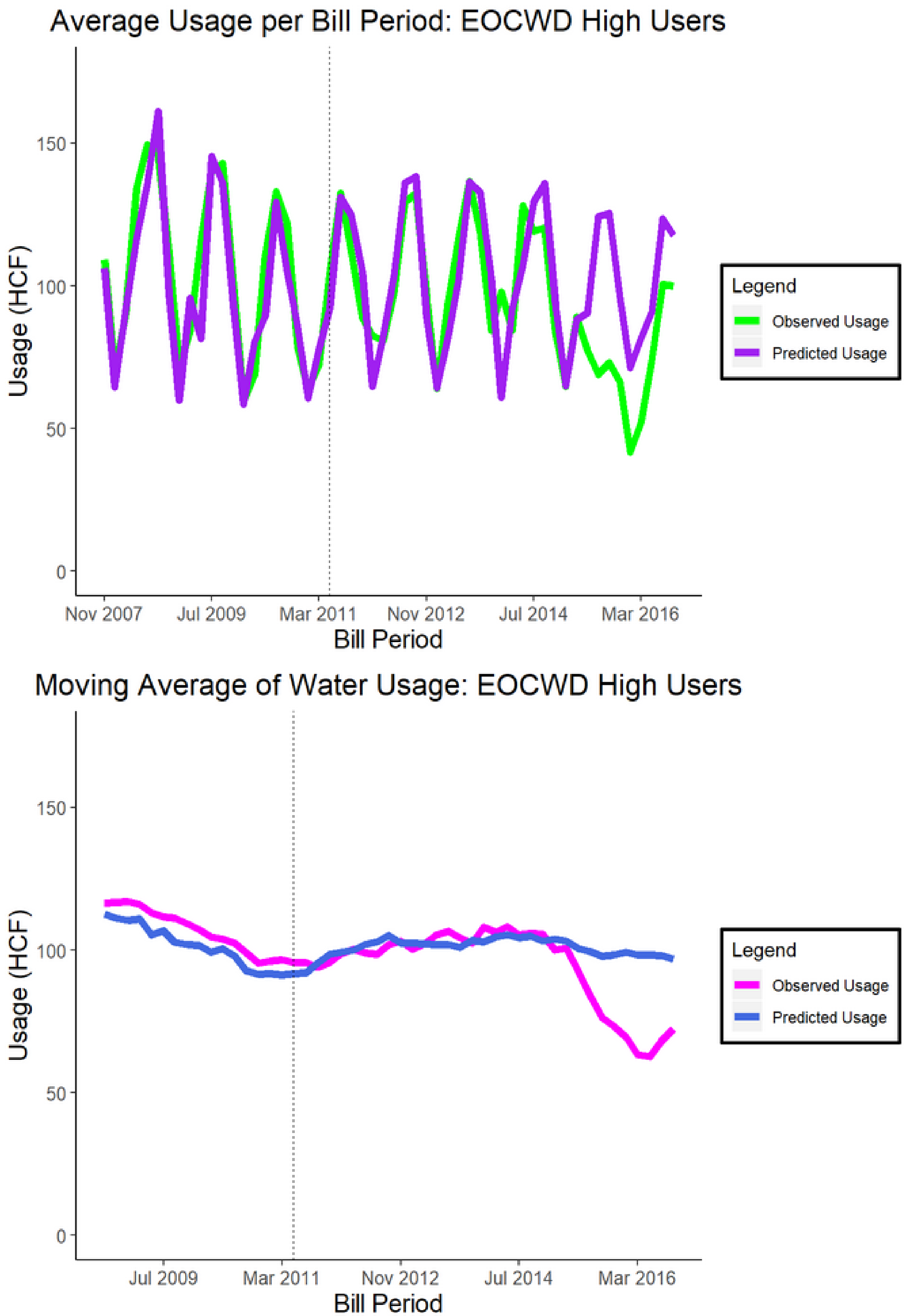
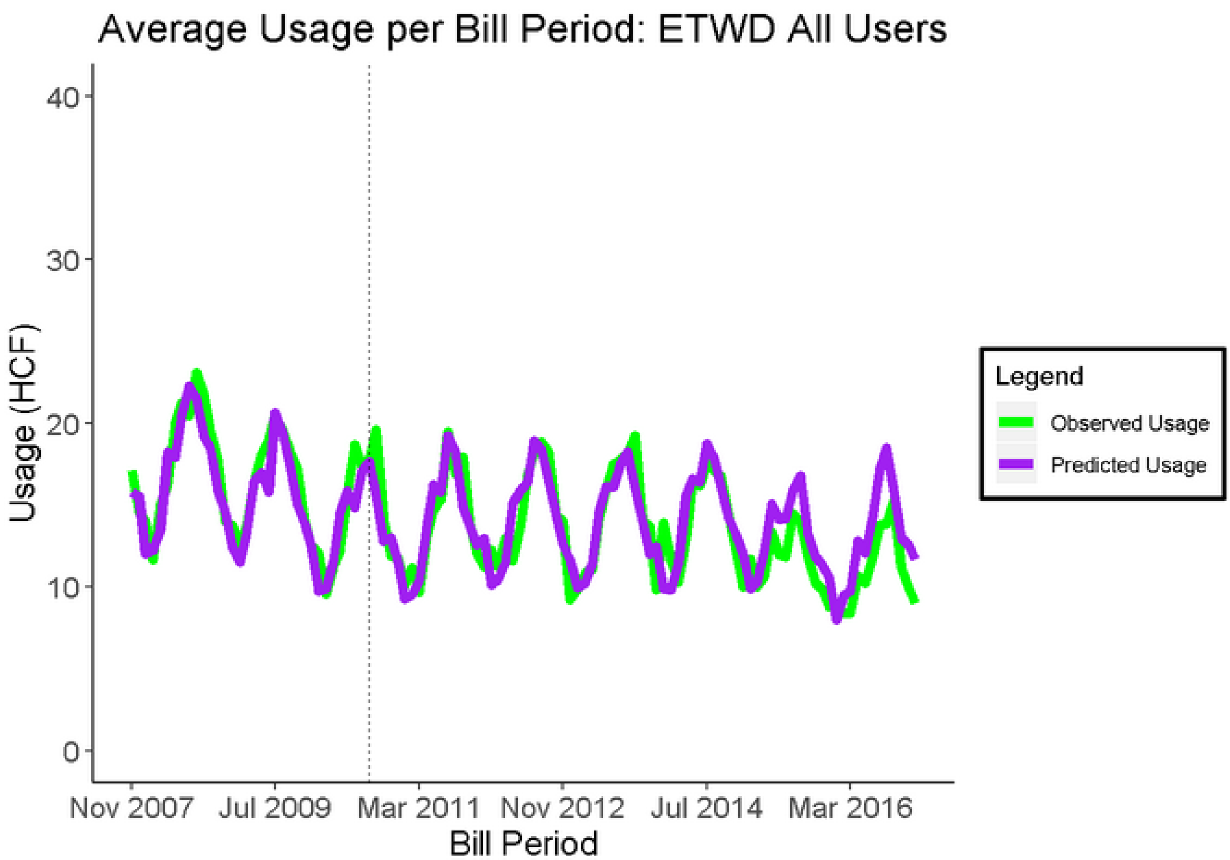


Table 7. Detailed Results for ETWD

ETWD			
Accounts (Total)	3497		
Savings (Total)	128533	*Adj. R2*	0.713
Savings (Total%)	3.5%	*β (log Price)*	-0.417
Drought Savings (Total)	128717	*β (ETo)*	0.083
Drought Savings (Total%)	3.5%	*β (ConsRestrict)*	-0.102
Accounts (Low)	1166		
Savings (Low)	29789	*Adj. R2*	0.575
Savings (Low%)	3.9%	*β (log Price)*	-0.490
Drought Savings (Low)	26342	*β (ETo)*	0.077
Drought Savings (Low%)	14.5%	*β (ConsRestrict)*	-0.104
Accounts (Med)	1166		
Savings (Med)	47288	*Adj. R2*	0.442
Savings (Med%)	4.0%	*β (log Price)*	-0.385
Drought Savings (Med)	42470	*β (ETo)*	0.087
Drought Savings (Med%)	15.0%	*β (ConsRestrict)*	-0.113
Accounts (Hi)	1165		
Savings (Hi)	70923	*Adj. R2*	0.541
Savings (Hi%)	4.0%	*β (log Price)*	-0.377
Drought Savings (Hi)	65253	*β (ETo)*	0.087
Drought Savings (Hi%)	15.9%	*β (ConsRestrict)*	-0.089

Figure 5. Results for ETWD (All Users)



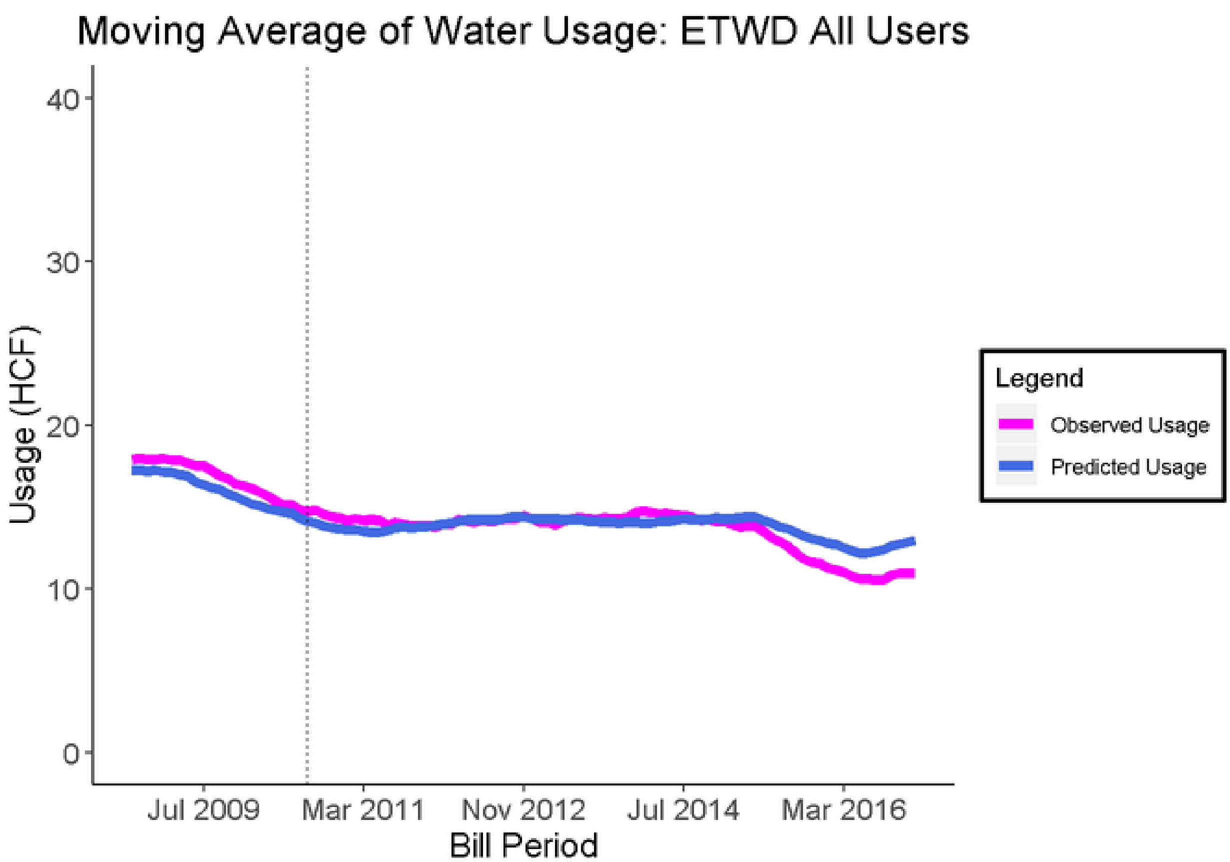
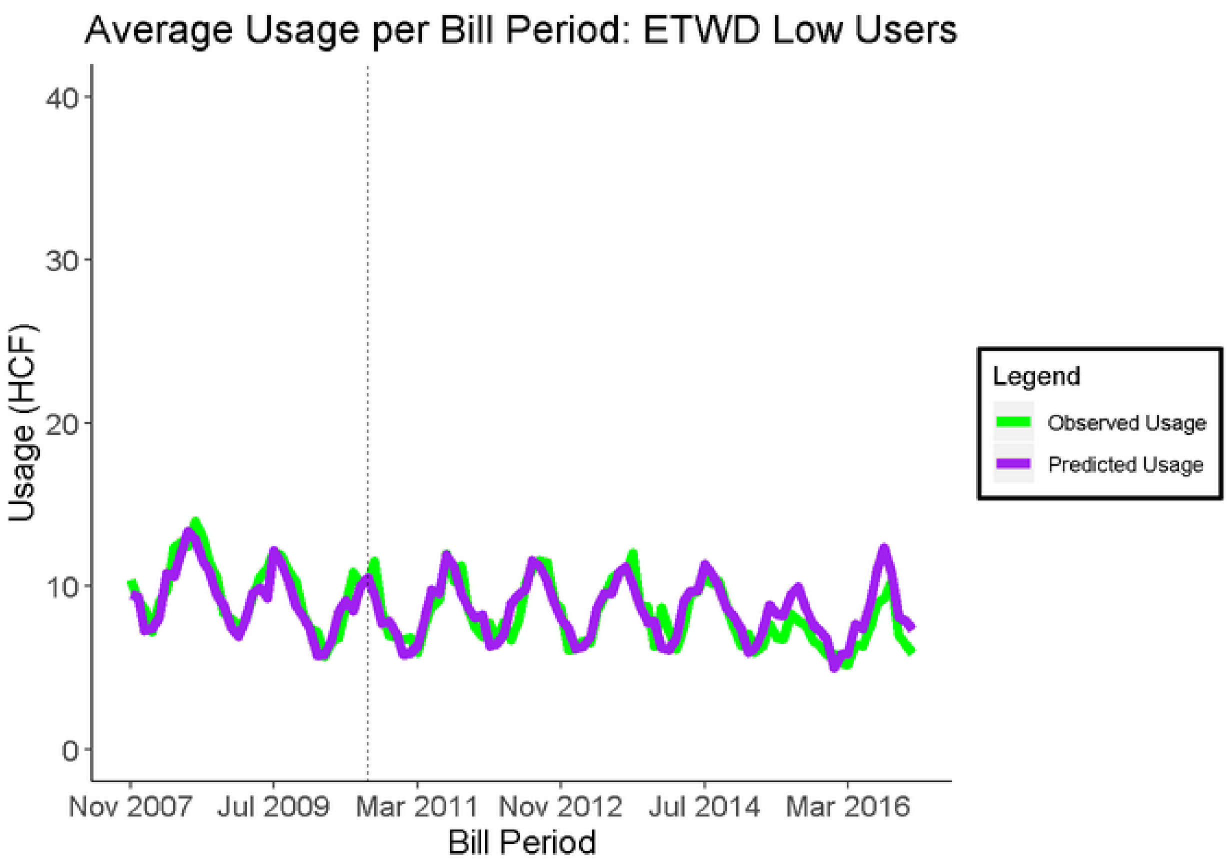


Figure 6. Results for ETWD (Low-Volume Users)



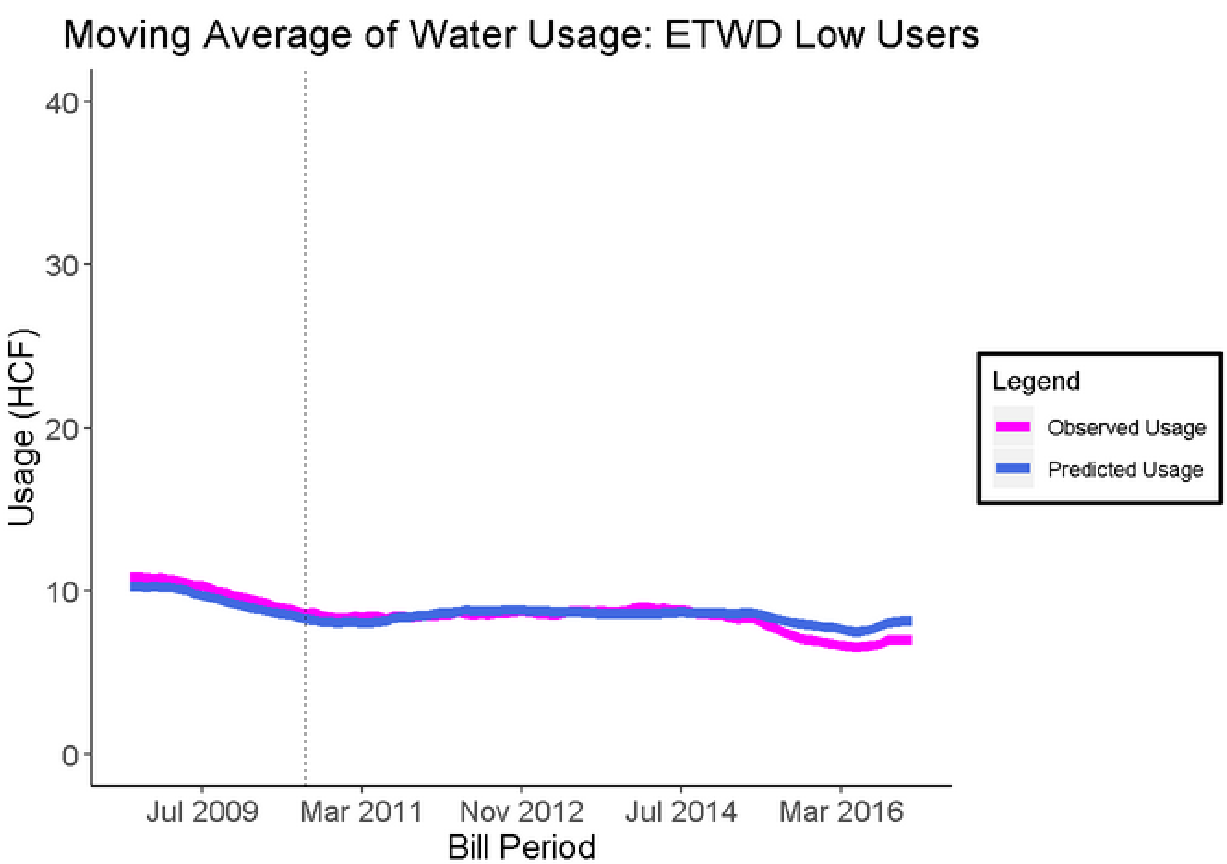
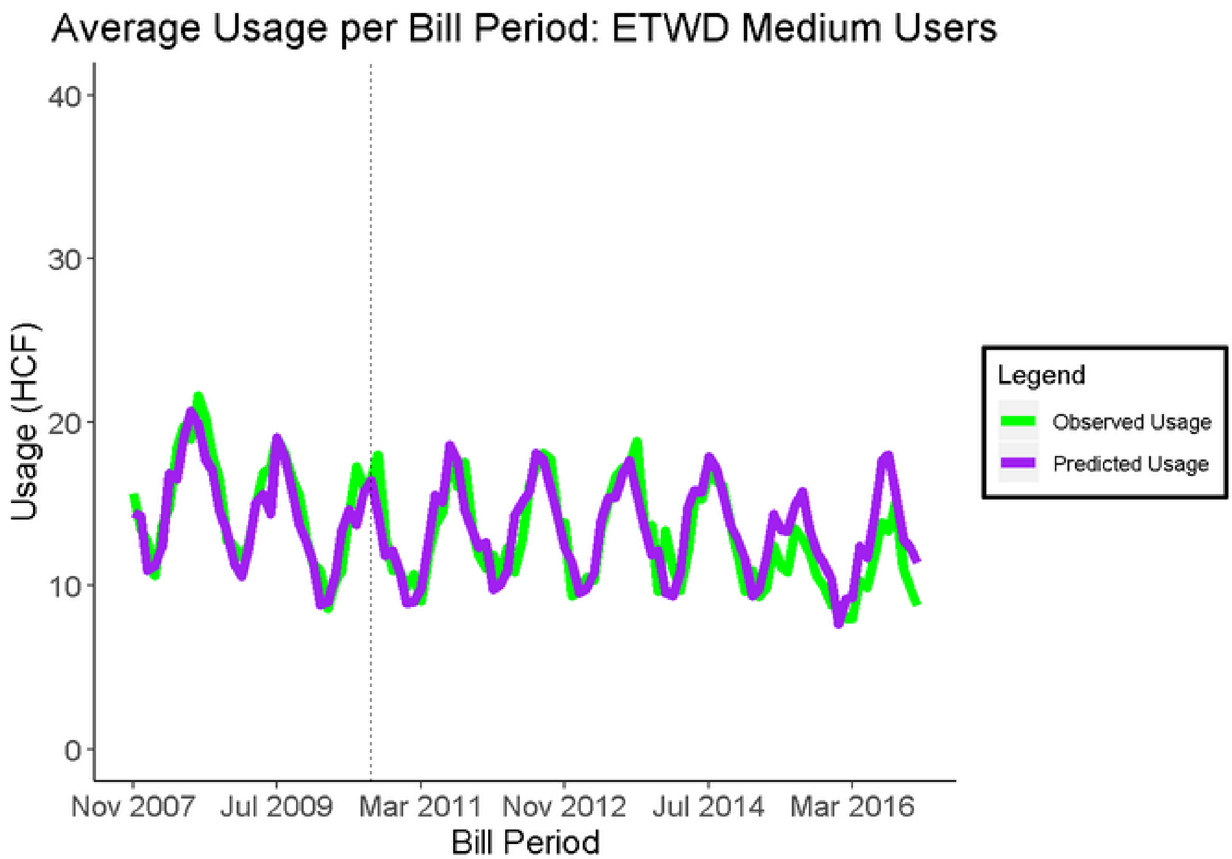


Figure 7. Results for ETWD (Medium-Volume Users)



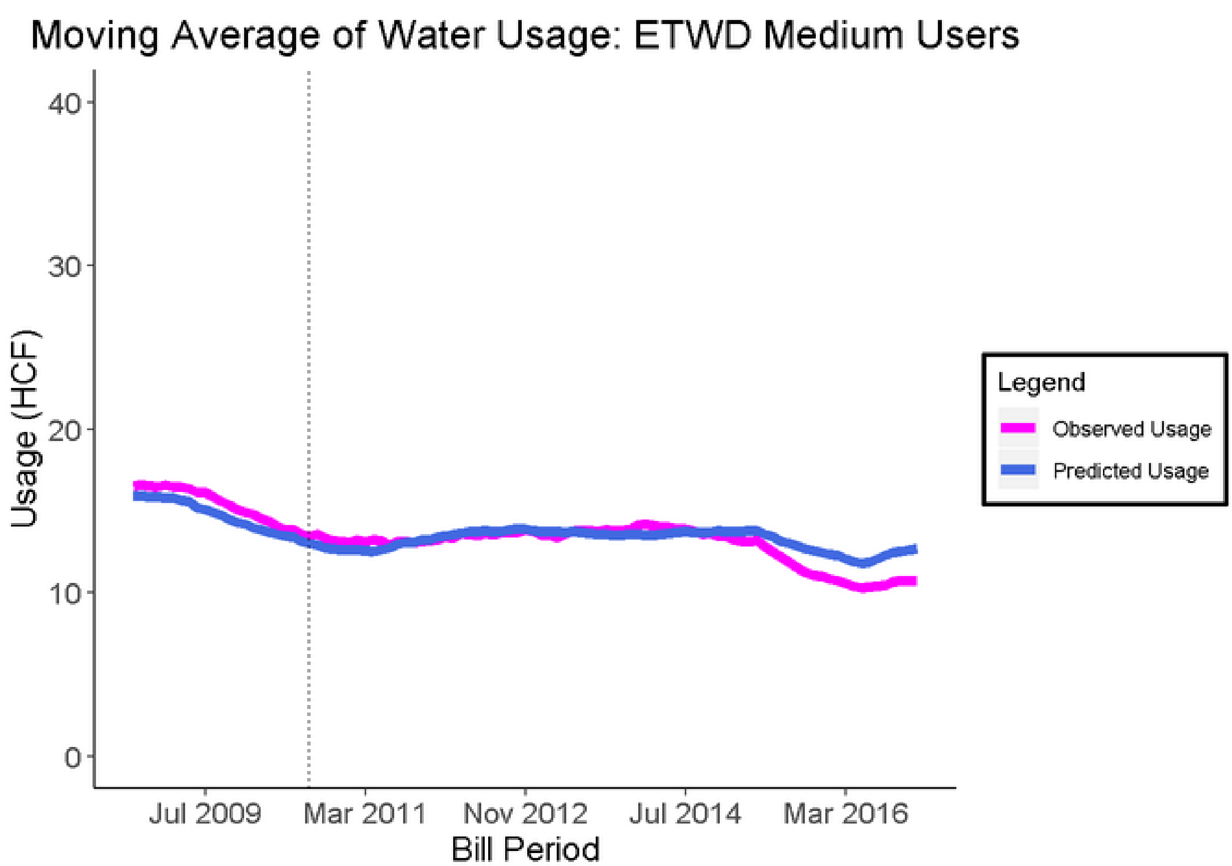
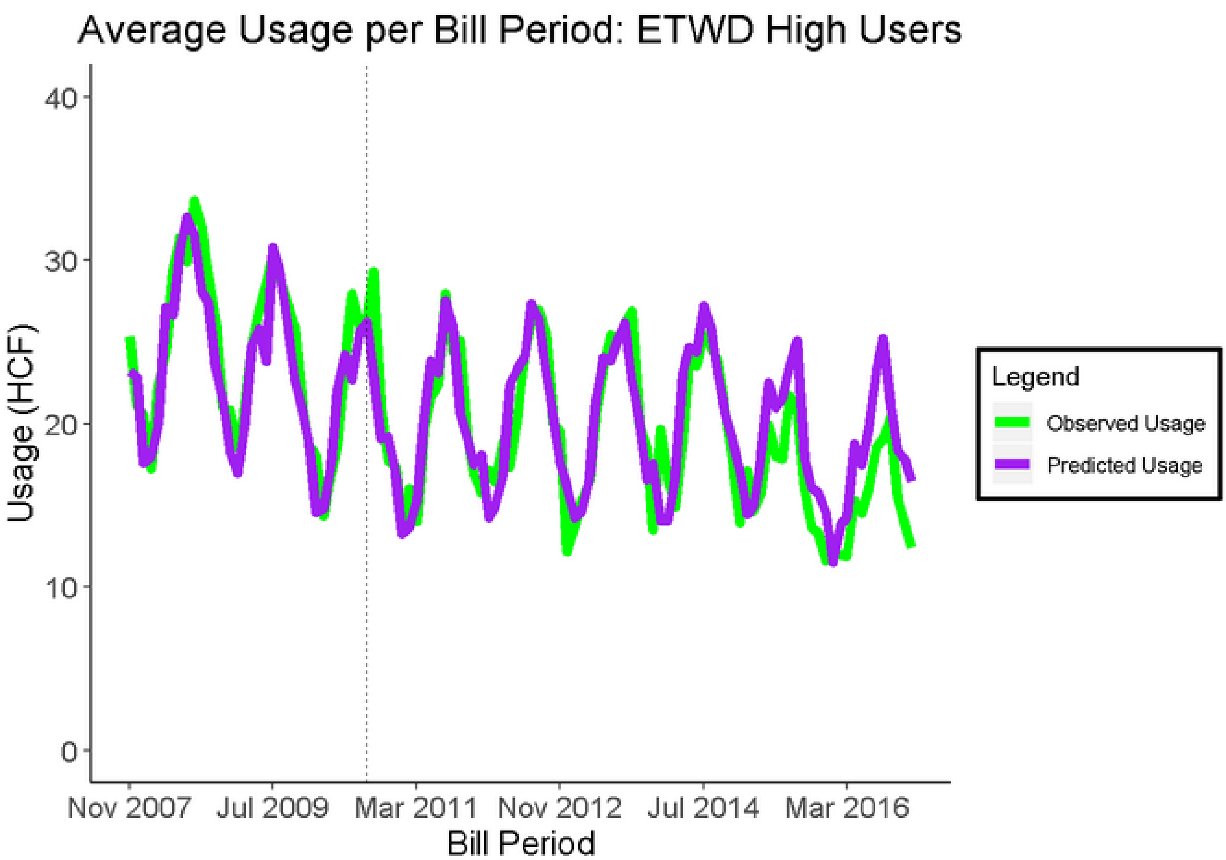


Figure 8. Results for ETWD (High-Volume Users)



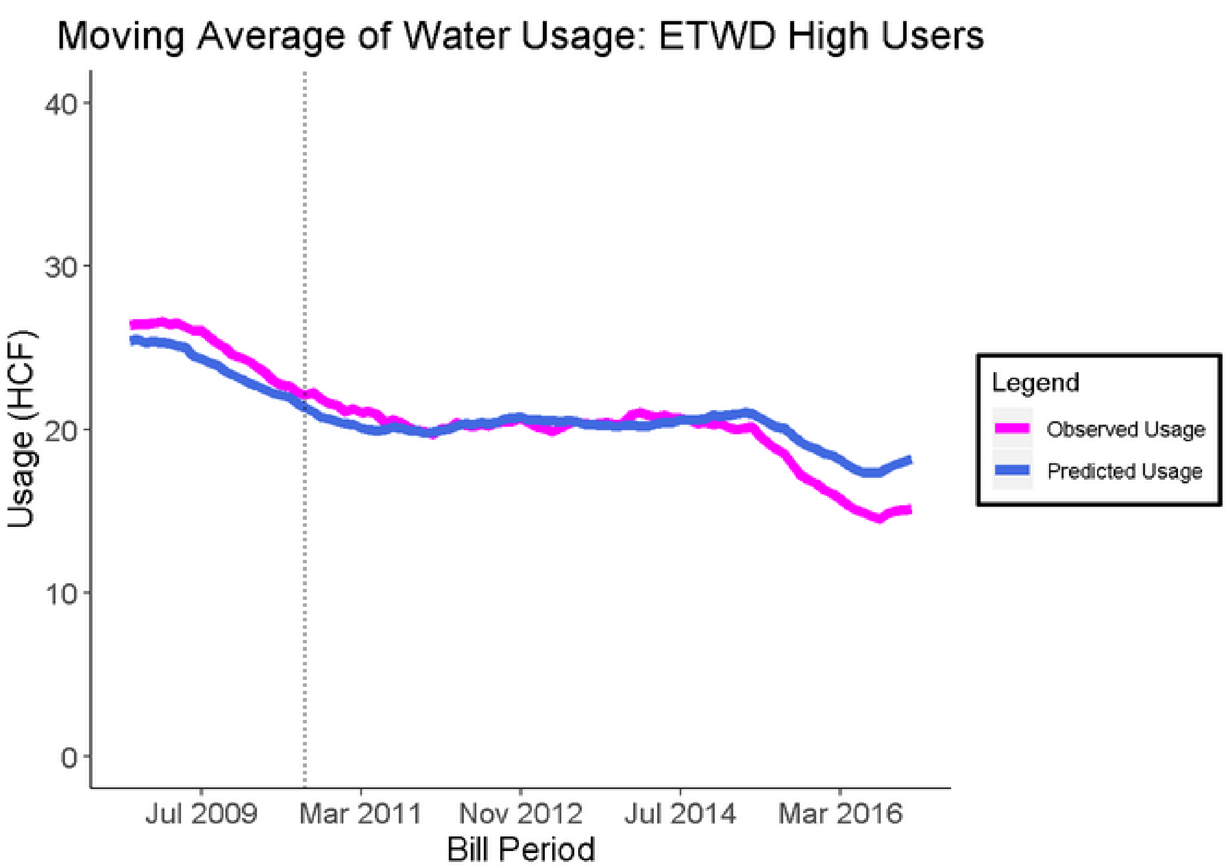
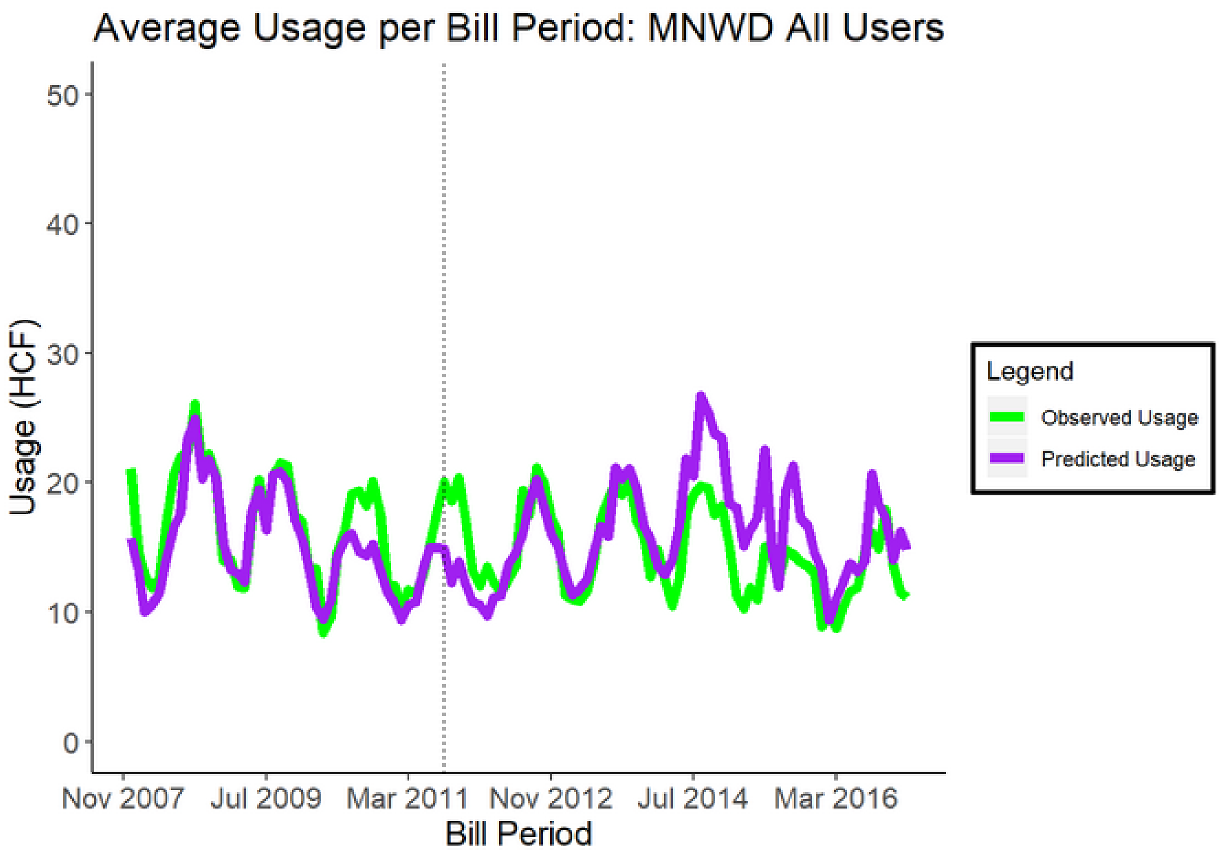


Table 8. Detailed Results for MNWD

MNWD			
Accounts (Total)	14828		
Savings (Total)	1409080	*Adj. R2*	0.813
Savings (Total%)	9.1%	*β (log Price)*	-2.392
Drought Savings (Total)	690761	*β (ETo)*	0.124
Drought Savings (Total%)	15.3%	*β (ConsRestrict)*	-0.022
Accounts (Low)	4943		
Savings (Low)	502313	*Adj. R2*	0.742
Savings (Low%)	19.0%	*β (log Price)*	-3.136
Drought Savings (Low)	38111	*β (ETo)*	0.067
Drought Savings (Low%)	6.0%	*β (ConsRestrict)*	0.056
Accounts (Med)	4943		
Savings (Med)	217363	*Adj. R2*	0.520
Savings (Med%)	5.1%	*β (log Price)*	-1.796
Drought Savings (Med)	206935	*β (ETo)*	0.141
Drought Savings (Med%)	15.9%	*β (ConsRestrict)*	-0.036
Accounts (Hi)	4942		
Savings (Hi)	785982	*Adj. R2*	0.660
Savings (Hi%)	9.1%	*β (log Price)*	-2.041
Drought Savings (Hi)	543483	*β (ETo)*	0.159
Drought Savings (Hi%)	20.2%	*β (ConsRestrict)*	-0.070

Figure 9. Results for MNWD (All Users)



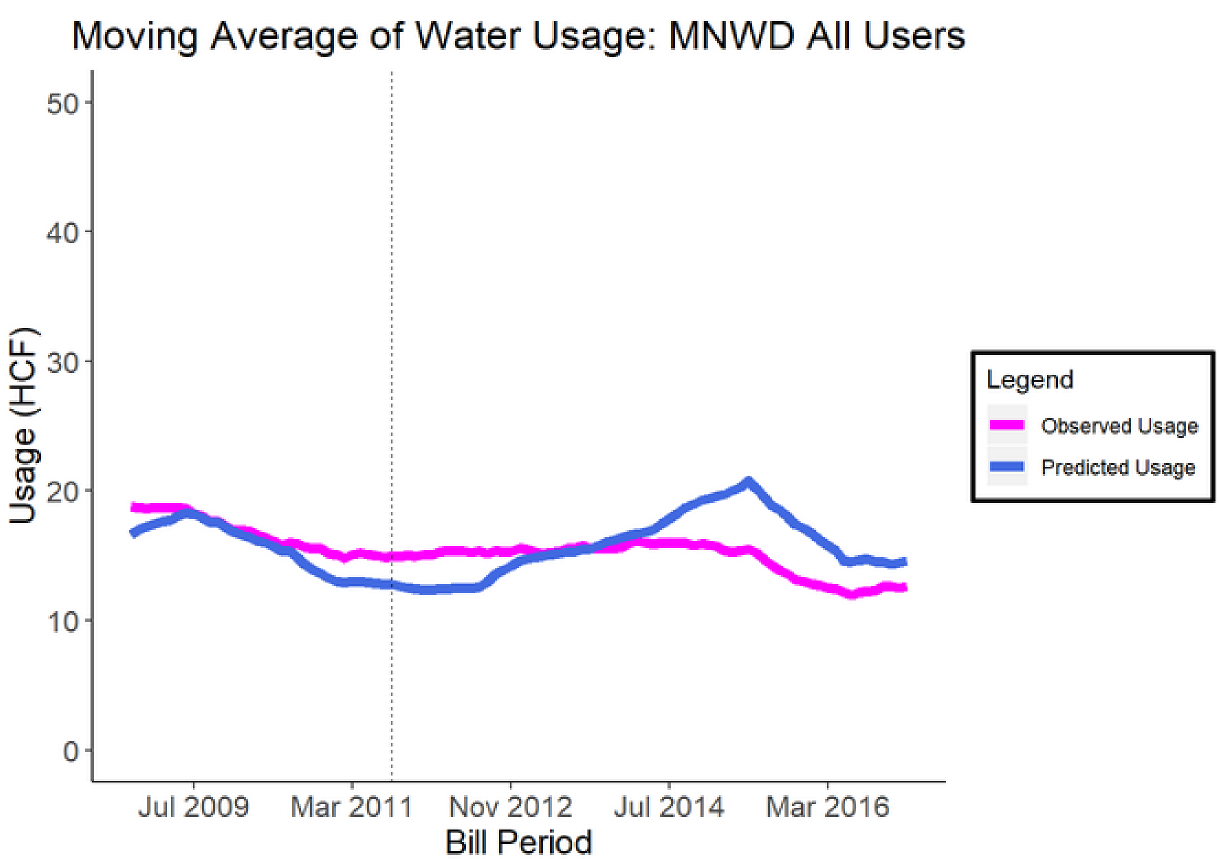
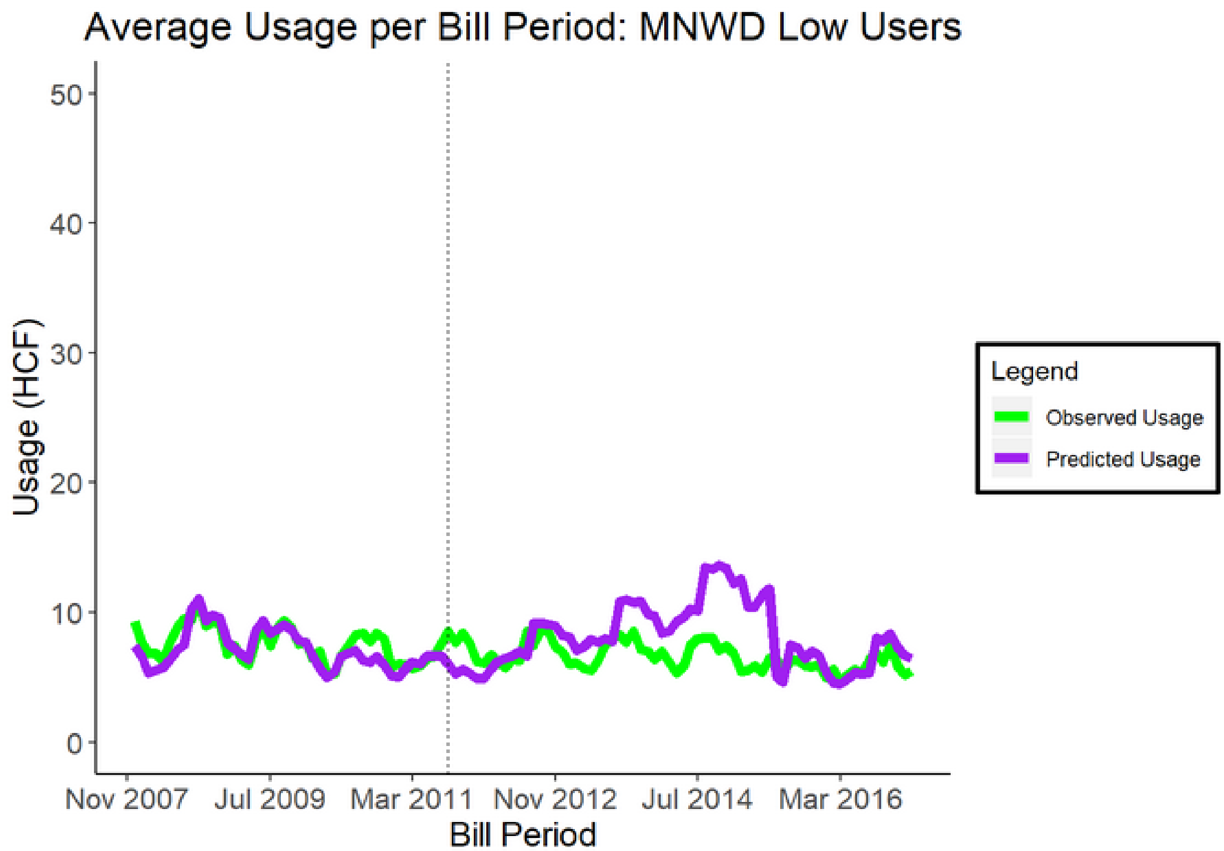


Figure 10. Results for MNWD (Low-Volume Users)



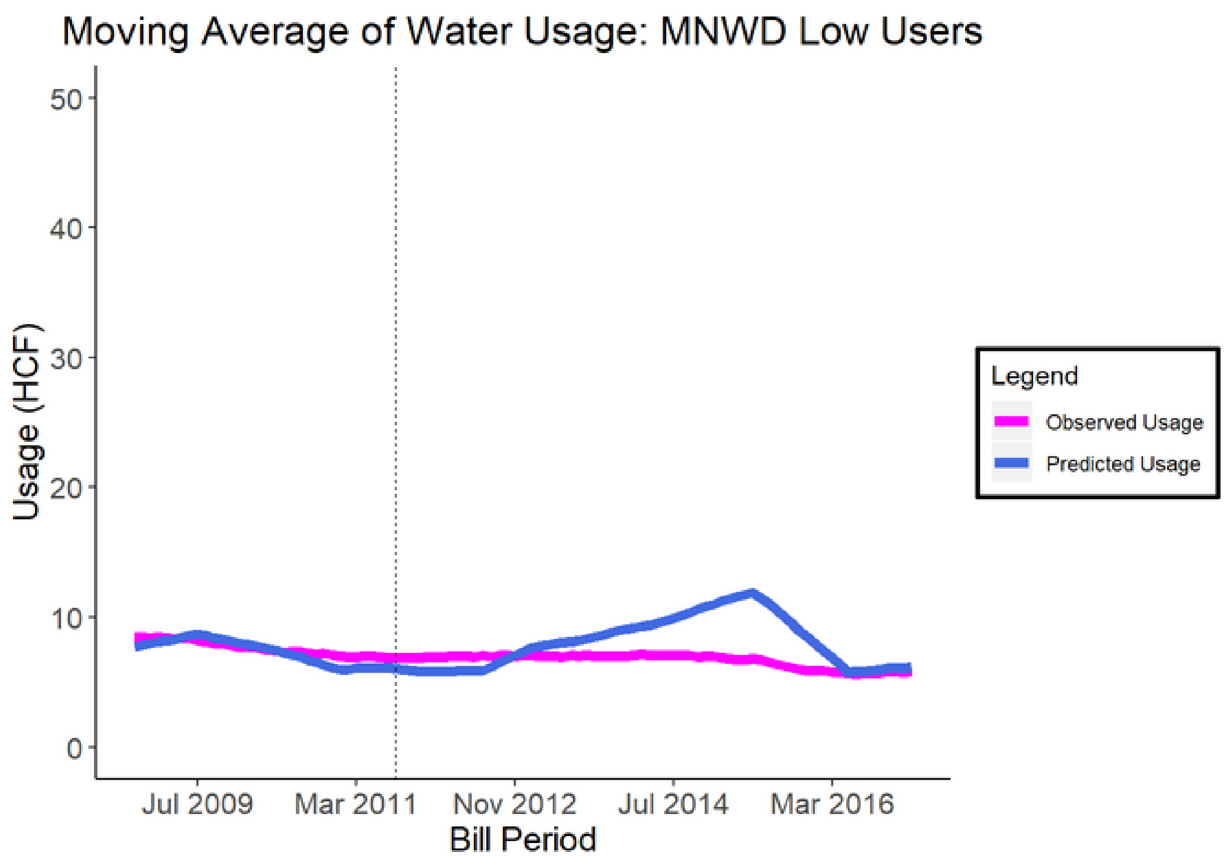
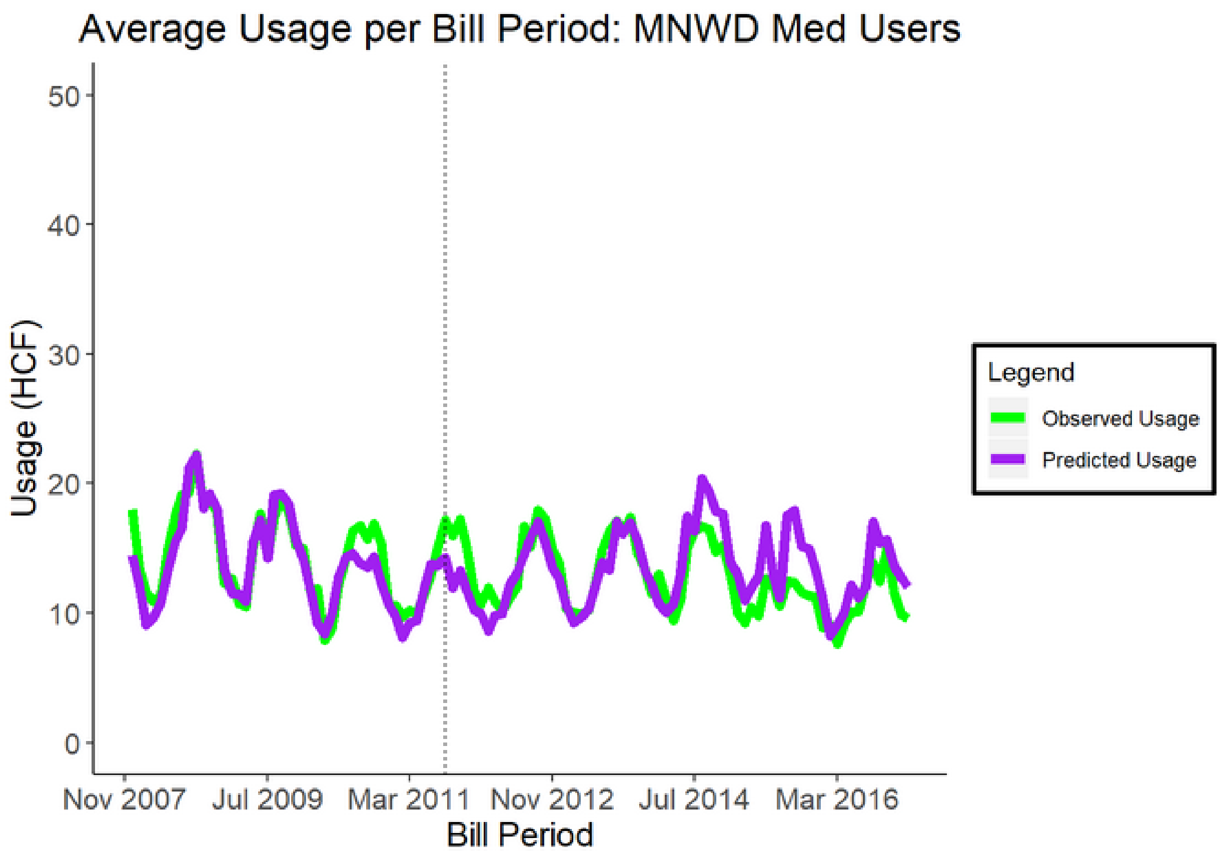


Figure 11. Results for MNWD (Medium-Volume Users)



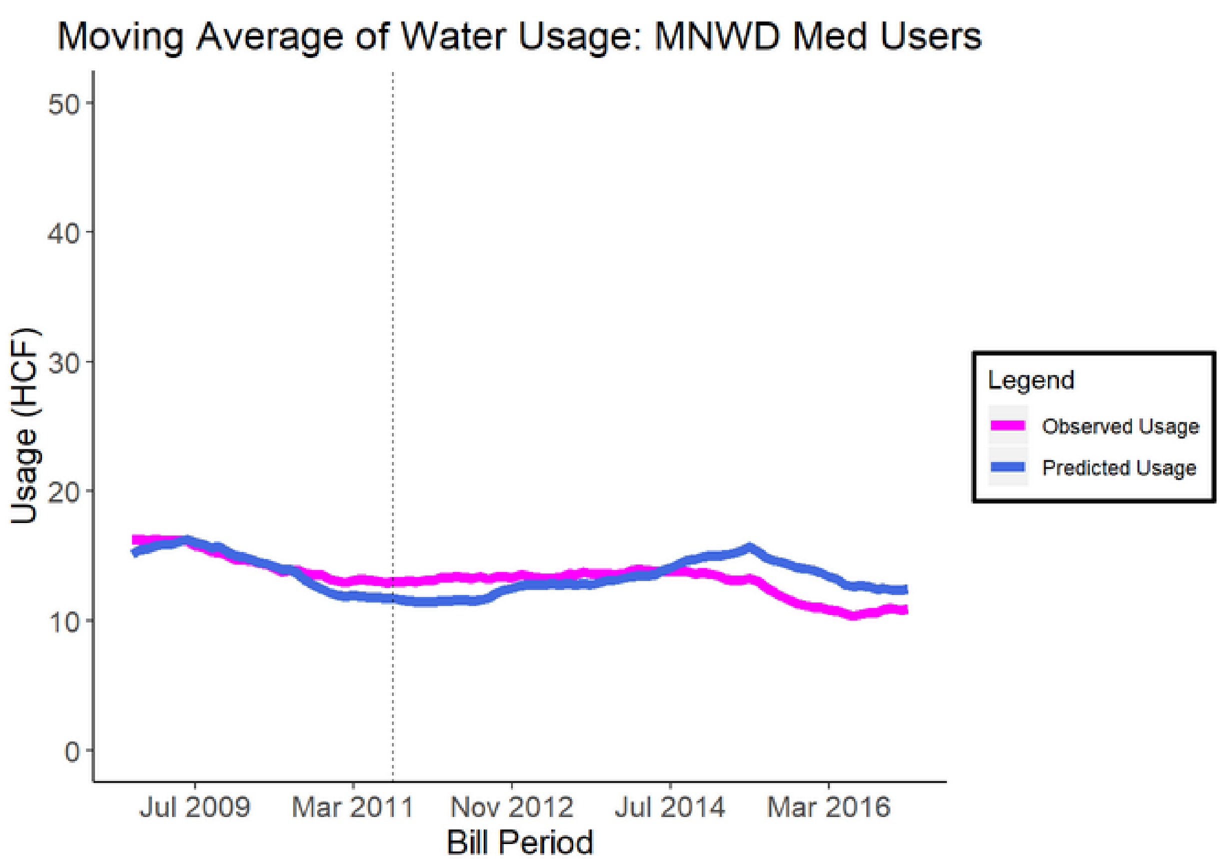


Figure 12. Results for MNWD (High-Volume Users)