



**2016-2035**

**WATER RESOURCE PLAN**

**APPENDIX 5**



## **APPENDIX 5-1**

### **Prioritized Main Replacement Program**



# Prioritized Main Replacement Program

August 2015



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## **Executive Summary**

The United States has entered the replacement era in which we need to begin rebuilding our water system infrastructure installed by earlier generations according to the American Water Works Association. Much of our drinking water infrastructure is nearing the end of its useful life and approaching the age at which it needs to be replaced. Significant investment will be required if we are to maintain the current level of water service Americans enjoy today.

The purpose of this inaugural effort was to ensure the viability, integrity and reliability of the water system for our community by developing prioritized short-term and long-term plans for water main renewal. Truckee Meadows Water Authority (TMWA) staff inventoried and analyzed existing water main infrastructure condition and service level. A scoring system was developed for prioritization primarily driven by 24 years of leak history as the best indicator of existing pipe condition. Finally, TMWA performance levels were compared to national metrics in order to guide ongoing best practices and decision making in regards to water main rehabilitation and replacement.

Results show TMWA's exceptional reliability and water main infrastructure integrity when compared nationally to public water system annual break rates, service levels and water produced but not billed. Coordination with local agencies should continue as this approach has proved to be the most cost effective and least disruptive to main replacement and rehabilitation for TMWA customers and the community. Furthermore, the current \$5 million dollar annual funding level is appropriate while expenditure requirements are expected to grow to \$18 million dollars annually by 2050. TMWA debt management activities will allow greater cash flow to fund water main rehabilitation and replacement expenditures into the future.

## **Findings and Recommendations**

### **Short-Term Plan:**

- Continue to coordinate water main rehabilitation and replacement projects with the City of Reno, City of Sparks, RTC, NDOT and Washoe County street reconstruction and utility projects. Integrating utility work prior to or concurrently with other agencies' projects has proved to be the most cost efficient and least disruptive approach to water main renewal for TMWA customers. TMWA may move forward independently with some priority projects as budgets allow.
- TMWA delivers exceptional reliability as measured by a low leak rate system-wide as well as for the top prioritized mains. TMWA's top 10 prioritized mains offer service levels of 0.3 to 1.1 leaks per 1,000 feet per year. When considering only internal costs, three breaks per 1,000 feet per year justify open-trench replacement while rehabilitation technologies can be cost-effective at two breaks per year. Therefore, no immediate action is warranted to address TMWA's prioritized mains outside of current best practices.
- Where rehabilitation or replacement are considered, priority should be focused on steel, cast iron, concrete cylinder and riveted steel water mains installed prior to 1960. These pipe materials makeup 12 percent of TMWA's water system inventory but account for 60 percent of recorded leaks. In addition, 90 percent of resulting prioritized mains were installed before 1960.

### Long-Term Plan:

- Monitor leak/break rates as a measurement of pipe condition, performance, and durability. Consider rehabilitation or replacement as service levels decline or field investigations and maintenance experience validate deteriorating pipe condition and increase the risk of failure.
- Continue to collect and maintain data necessary to build a comprehensive asset management and prioritization program. Incorporate merger-acquired water mains with future updates.
- Budget and plan for increasing water main rehabilitation and replacement costs as facilities age and approach the end of their expected service life. Expenditures are expected to grow to over \$18 million dollars annually by 2050. Debt management activities under consideration will allow greater cash flow to fund rehabilitation and replacement expenditures into the future.

## **Methodology**

The purpose of this inaugural effort was to inventory and analyze existing TMWA water main infrastructure condition and service level to develop prioritized short-term and long-term plans for water main renewal. Water services were not included in this analysis. Stated goals and objectives were to:

1. Incorporate the likelihood and consequence of water main failure to reduce total system risk, associated unplanned outages and emergency repair costs.
2. Prioritize main rehabilitation and replacements based on risk and coordination with local agencies to maximize benefits and minimize costs.
3. Ensure the viability, integrity and reliability of the water system for our community.

To identify priority mains in TMWA's distribution system, the likelihood and consequence of failure for each pipe segment was estimated using data contained in our geographic information system (GIS). The likelihood of failure included such attributes as material, age, leak history, soil condition, proximity to railroads and fault lines and higher static pressure areas. The consequence of failure included diameter, hydraulic criticality, and high volume users. Each criterion was scored and mains subsequently ranked according to risk.

The results of this initial effort were driven primarily by the likelihood of failure and specifically, the leak history data as the best indicator of existing pipe condition. Datasets including critical customers, difficult access for maintenance, potential damage to surrounding high-value areas, the extent of customer outages and traffic interruptions were not available but may be incorporated in future updates. Locate the full methodology in Appendix A.

## **Short-Term Prioritization Plan**

### Street and Highway Program

Coordination with local agencies has proved to be the most cost effective and least disruptive approach to main replacement and rehabilitation for TMWA customers and the community. The Street and Highway Main Replacement Program has been funded at an average rate of \$5 million dollars per year since the inception of TMWA in 2001. The average rate of main replacement under this program has been 8,000 feet per year. TMWA works cooperatively with our local agencies to keep projects on time and within budget.

### Break and Leak Rates, Service Level, and Non-Revenue Water

The American Society of Civil Engineers' *2013 Report Card for America's Infrastructure* graded the nation's water infrastructure a D+ and reported that there are an estimated 240,000 water main breaks per year in the United States. Division results in an average break rate of 24 breaks per 100 miles annually since it is estimated that there are a little over one million miles of water mains installed in the U.S.

According to the American Water Works Association (AWWA), the median level of breaks and leaks has ranged from 26 to 49 per 100 miles since 2004 (*Benchmarking Performance Indicators for Water and Wastewater Utilities: 2013 Survey Data and Analyses Report*). The 75<sup>th</sup> percentile ranged up to 89 while the 25<sup>th</sup> percentile was down to zero in one year. More typically the break rate is in the range of 15 to 20 leaks and breaks per 100 miles annually. While TMWA has not differentiated between leaks and breaks historically, the AWWA defines leaks and breaks as follows:

*Leak: A leak refers to an opening in a distribution pipeline, valve, hydrant, appurtenance or service connection that is continuously losing water.*

*Break: A break refers to physical damage to a pipe, valve, hydrant, or other appurtenance that result in an abrupt loss of water.*

TMWA's system-wide water main leak rate is very low at 3 leaks per 100 miles annually indicating very high service levels currently exist. This leak rate is based on 24 years of leak history data collected beginning in March of 1989 through February of 2013. In all, 1,067 leaks on water mains have been documented in that time (including 63 leaks due to third party damage) equating to an average total number of 45 leaks annually.

Another way to express service level is the number of leaks per year per 1,000 feet of installed water main. The TMWA system-wide rate is 0.006 leaks per 1,000 feet per year while the rates for our top 10 prioritized mains vary from 0.3 to 1.1 leaks per year. According to an AWWA Research Foundation Report, one to three breaks per 1,000 feet per year justify open trench replacement, depending on the number of services and traffic disruption involved. Rehabilitation is cost effective at 0.5 to two breaks per 1,000 feet per year according to this report. These decision threshold recommendations take into account the internal and external costs involved and customer attitudes and acceptance of the frequency and duration of service disruptions (*Customer Acceptance of Water Main Structural Reliability*, AWWA Research Foundation, 2005). Therefore, no immediate action is warranted to address TMWA's prioritized mains outside of current best practices.

View TMWA's top 10 prioritized mains in Table 1. All are steel or cast iron pipes installed prior to 1950 and have leak rates of 0.3 to 1.1 leaks per 1,000 feet per year.

**Table 1: TMWA's Top 10 Prioritized Mains**

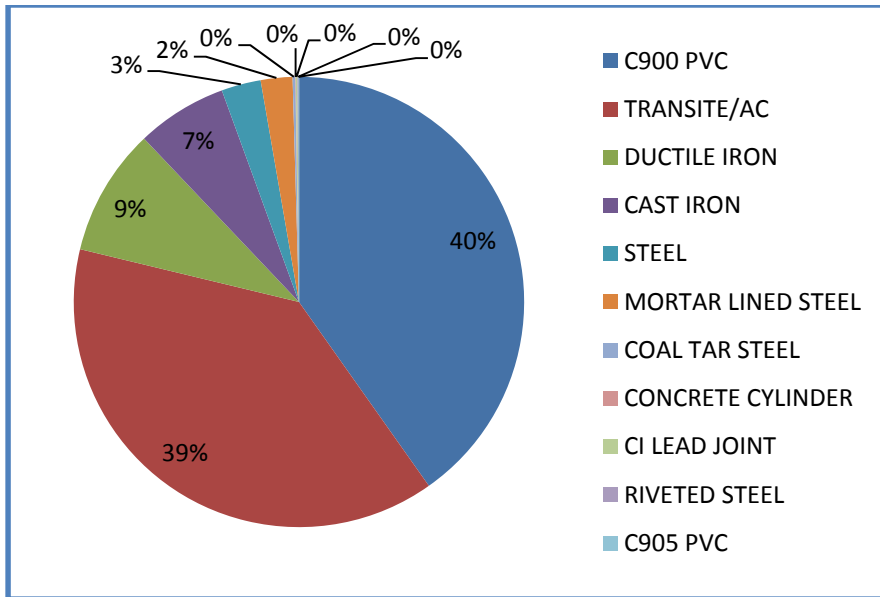
Main Location	Diameter and Material	Length (ft)	Year Installed	Number of Leaks (1989-2013)	Number of Services	Leak Rate (annual leaks per 1,000 feet)
Plumas Street	12-inch steel	3,900	1948	28	32	0.3
Washington Street	6-inch steel	1,700	1925	36	60	0.9
Southridge Drive	6-inch steel	1,600	1947	19	20	0.5
Stewart Street	6-inch steel	440	1920	12	23	1.1
Moran Street	4-inch cast iron	400	1926	10	17	1.0
Haskell Alley	4-inch cast iron	400	1926	8	15	0.8
Haskell Street	6-inch steel	310	1947	8	1	1.1
Humboldt Street	6-inch steel	310	1923	7	9	0.9
Daniel Drive	6-inch steel	1,080	1947	11	25	0.4
Bartlett Street	6-inch cast iron	820	1948	9	24	0.5

TMWA's low leak rate is also reflected in TMWA's comparatively small non-revenue water use. Non-revenue water refers to water that is produced but not billed or accounted for in customers' meters. Non-revenue water can be authorized (firefighting, hydrant testing, flushing) or result from unauthorized use and leakage. The national annual average public water system non-revenue water use is 16 percent per *Water Audits and Water Loss Control for Public Water Systems*, USEPA July 2013. TMWA's non-revenue water use has been estimated at 6 percent annually.

An exhibit showing TMWA's prioritized mains displayed geographically is included in Appendix B. Exhibits showing TMWA's top 10 prioritized mains in more detail are attached in Appendix C. A table listing the top 100 prioritized mains is shown in Appendix D. Appendices F through K exhibit criterion used in the prioritization including leak history.

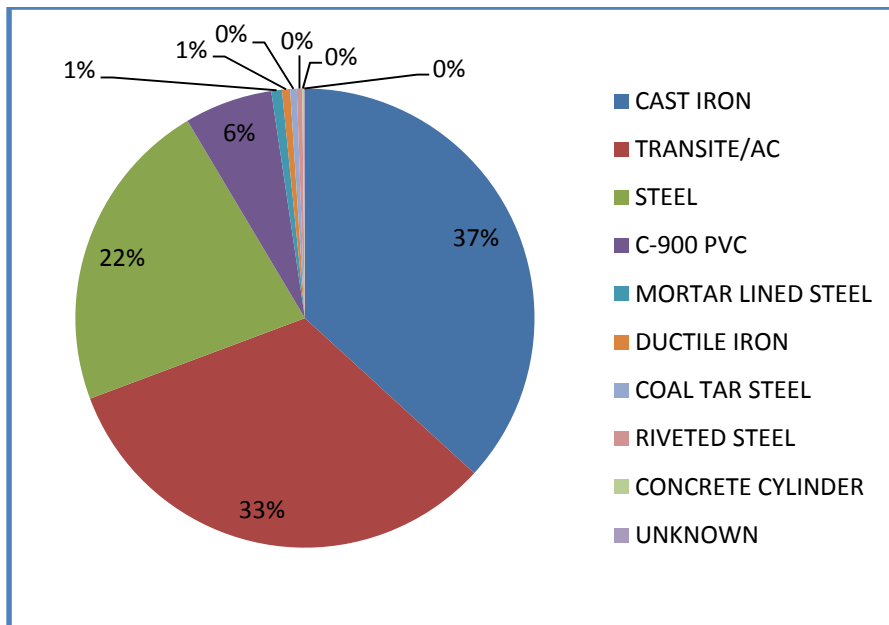
*Prioritized Water Main Materials - Steel, Cast Iron, Concrete Cylinder, Riveted Steel*

TMWA's water system consists of approximately 539 miles of polyvinyl chloride (PVC) pipe, 517 miles of asbestos cement (AC) or Transite pipe, 123 miles of ductile iron (DI) pipe, 89 miles of cast iron (CI) pipe, 72 miles of steel pipe, and a small amount of concrete cylinder pipe. The figure on the next page shows the percentage of pipe by material in TMWA's system.

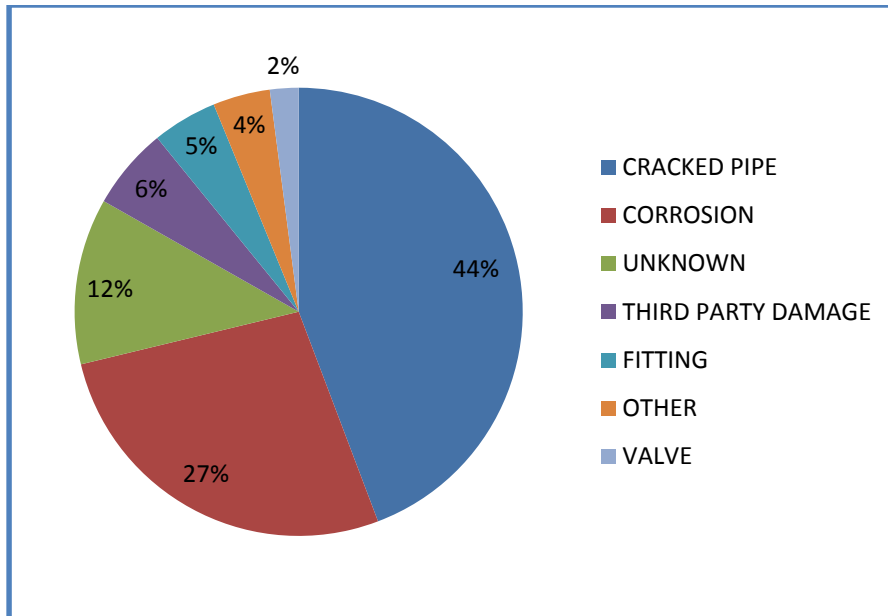


**Figure 1: Percentage of Main by Material**

The following two figures show the percentage of leaks by material and by type of failure. Leaks on steel mains are most commonly caused by corrosion while cracking is most common on cast iron and asbestos cement materials.

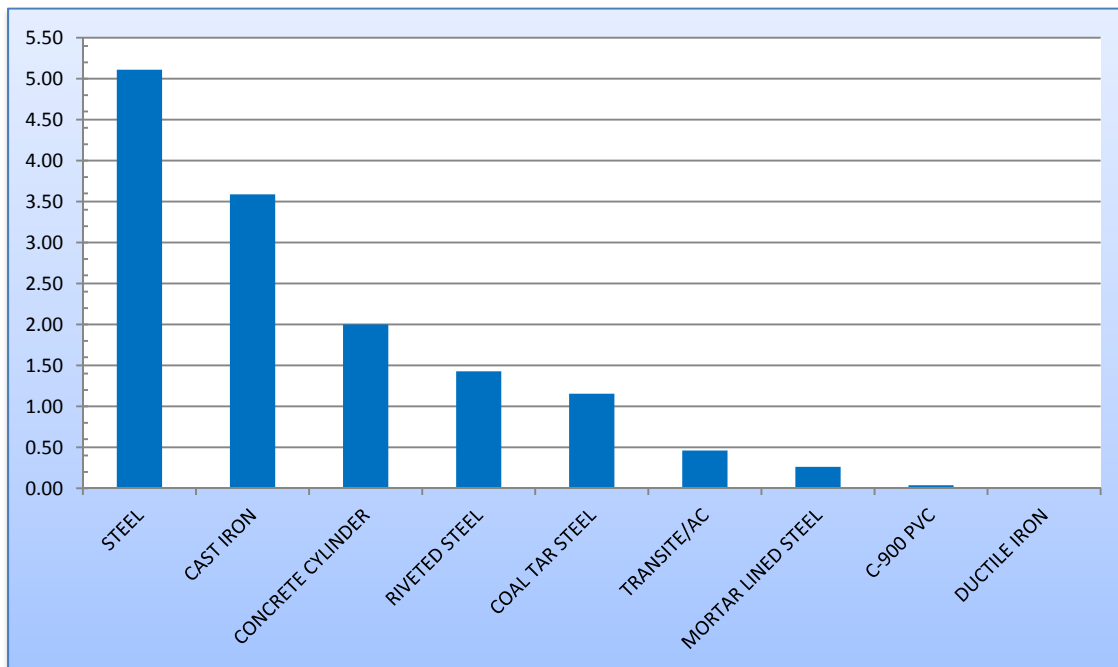


**Figure 2: Percentage of Leaks by Material**



**Figure 3: Percentage of Leaks by Type**

The graphic below illustrates that steel, cast iron, concrete cylinder, and riveted steel pipes have the highest number of leaks per mile by material and, therefore, should be the focus of TMWA's prioritized main replacement program. As previously mentioned, these pipe materials makeup only 12 percent of TMWA's water system inventory but account for 60 percent of recorded water main leaks.



**Figure 4: Number of Leaks per Mile by Material**

Additionally, the age of pipe installations, as well as soil conditions and early laying practices, are linked to prioritized main results. Ninety percent of resultant prioritized mains from this analysis were installed prior to 1960. The table below shows that TMWA has 28.5 miles of these mains that were installed prior to 1960.

**Table 2: Steel, Cast Iron, Concrete Cylinder Pipe Installed Prior to 1960**

Main Diameter	Length in Feet Installed Prior to 1960					Total by Size (feet)
	Steel	Cast Iron	Riveted Steel	MLS	CCP	
4"	0	569	0	0	0	569
6"	3,596	52,071	0	0	0	55,667
8"	696	26,194	0	0	0	26,890
10"	1,074	702	1,130	0	0	2,906
12"	62	2,990	10,625	0	0	13,677
14"	12,687	0	0	0	1,063	13,750
16"	0	0	0	1,217	0	1,217
18"	31	0	0	0	0	31
22"	5	0	0	0	0	5
24"	34,757	0	0	1,122	0	35,879
42"	50	0	0	0	0	50
Total Feet	52,958	82,526	11,755	2,339	1,063	150,641
					Total Miles	28.5

Why Not Prioritize Asbestos Cement Mains?

While asbestos cement water mains account for 33 percent of recorded water main leaks at TMWA, the number of leaks is low at less than 0.5 per mile. The exhibit in Appendix E shows asbestos cement pipe leak history appears quite random geographically making it is difficult to predict where future leaks might occur. Asbestos cement mains should be replaced if determined necessary based on information for a specific main in conjunction with the Street and Highway Main Replacement Program.

**Long-Term Prioritization Plan**

Continue Service Level Monitoring

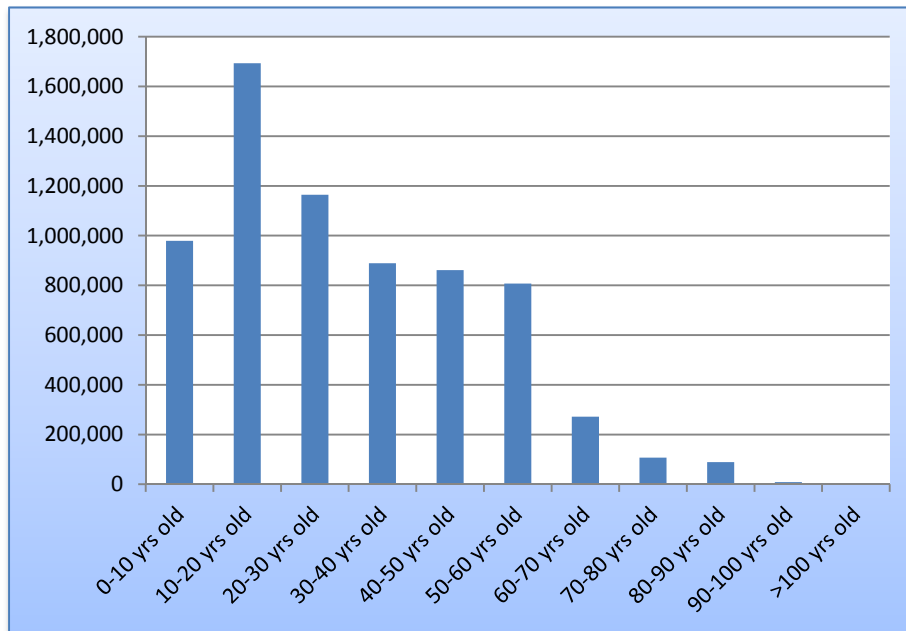
TMWA will continue to monitor leak rates as a measurement of pipe condition, performance, and durability. Rehabilitation or replacement will be evaluated as service levels decline or field investigations and maintenance efforts validate deteriorating pipe condition and increased risk of failure. Engineering staff will perform alternatives evaluations to determine whether or not priority pipes can be abandoned, rerouted, or should be rehabilitated or replaced. Replacements will continue under the existing Street and Highway Main Replacement Program budget item or will be capitalized as necessary.

Data Collection and Maintenance

Beyond TMWA's existing GIS and computerized maintenance management system Cityworks, additional data and analyses tools will be necessary for more advanced approaches to a long-term main prioritization plan. Ultimately, a life cycle planning approach including development of aging functions and determination of the effective useful service life at the pipe level could prove useful. Future updates will also include newly acquired water mains in the analyses.

### Projection of Investment Requirements by Year to 2050

Much of the drinking water infrastructure nationwide is nearing the end of its useful life and approaching the age at which it needs replacement. Fortunately, TMWA's assets are generally newer than those in the eastern United States and Midwest. The figure below shows the age of installed length of main in TMWA's system by decade.



**Figure 5: Age of Installed Length of Main in Feet**

Nevertheless, significant investment will be required if we are to maintain the current level of water service Americans enjoy today. The AWWA has produced a report and tool for use by water utilities to project asset replacement costs through 2050 called the *Buried No Longer Pipe Replacement Modeling Tool* (Copyright 2013 AWWA). This tool scales the outcomes of the larger report for specific utility criteria such as size, replacement costs, pipe age, and materials. TMWA's results estimate the growth of replacement expenditures for water mains to approximately \$18 million dollars per year by 2050 (in 2012 dollars). Debt management activities under consideration will allow greater cash flow to fund rehabilitation and replacement expenditures into the future. Find the full results in Appendix L.

#### Further Reading

<http://www.infrastructurereportcard.org/a/#p/drinking-water/overview>

<http://www.infrastructurereportcard.org/a/#p/state-facts/nevada>

<http://water.epa.gov/type/drink/pws/smallsystems/upload/epa816f13002.pdf>

<http://www.awwa.org/Portals/0/files/legreg/documents/BuriedNoLonger.pdf>

**Appendix A**

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**Prioritized Main Replacement Analyses Methodology**

## **Main Rehabilitation and Replacement Prioritization Methodology**

### ***Purpose:***

Identify, budget and plan main rehabilitation or replacements based on risk. Coordinate with local agencies for maximum benefit and minimum cost to ensure the viability, integrity, and reliability of the water system for TMWA customers.

### ***Task:***

Develop a prioritized main replacement program using currently available information and technology incorporating the likelihood and consequence of failure to reduce total system risk, associated unplanned outages, and emergency repair costs.

### ***Part 1 Methodology:***

1. Estimate the likelihood of pipe failure:
  - a. Physical
    1. material
    2. age
    3. distribution staff field experience
  - b. Historical
    1. leak and break history
    2. maintenance records\*
  - c. Spatial
    1. soil conditions
    2. proximity to railroads, fault lines
  - d. Hydraulic
    1. high static pressure areas
2. Estimate the consequence of pipe failure:
  - a. Physical
    1. diameter
  - b. Spatial
    1. potential damage to surrounding high-value areas\*
    2. difficult access for maintenance or repairs\*
  - c. Hydraulic
    1. pipe hydraulic criticality
  - d. Customer and Public Relations
    1. outages to critical customers\*/high volume users
    2. extent of customer outages/population density/traffic interruptions\*
3. Calculate risk of failure and develop a prioritized list of main replacements

### ***Part 2 Methodology:***

1. Budget and plan renewal based on risk and coordination with local agencies.
  - a. Annually correlate to planned street and highway repair or utility work
  - b. Engineering alternatives evaluation
    1. abandon, reroute, rehabilitate or replace
  - c. Perform selected field condition assessments
  - d. Prepare preliminary designs and cost estimates

Note: \* Items were not included in this analysis.

**Appendix B**

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**Prioritized Mains by Risk Score**

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HOMELAND SECURITY INFORMATION

(NRS 239C.210)

**Appendix C**

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**Top 10 Prioritized Mains**

Main Location	Diameter	Material	Year Installed	Number of Leaks
PLUMAS ST	12-inch	steel	1948	28
WASHINGTON ST	6-inch	steel	1925	36
SOUTHRIDGE DR	6-inch	steel	1947	19
STEWART ST	6-inch	steel	1920	12
MORAN ST	4-inch	cast iron	1926	10
HASKELL ALLEY	4-inch	cast iron	1926	8
HASKELL ST	6-inch	steel	1947	8
HUMBOLDT ST	6-inch	steel	1923	7
DANIEL DR	6-inch	steel	1947	11
BARTLETT ST	6-inch	cast iron	1948	9
JUNIPER HILL RD	4-inch	steel	1948	6
BON REA WAY	4-inch	cast iron	1926	8
STEWART ST	6-inch	cast iron	1947	6
K ST	6-inch	cast iron	1952	6
W MOANA LN	12-inch	steel	1948	4
GENTRY WAY	8-inch	steel	1948	4
WHEELER AVE	8-inch	steel	1912	6
G ST	6-inch	steel	1947	4
LANDER ST	6-inch	cast iron	1930	4
COMSTOCK DR	6-inch	cast iron	1963	6
BASQUE LN	24-inch	steel	1960	4
MARY ST	4-inch	cast iron	1928	4
COLLEGE CT	4-inch	cast iron	1931	5
GRASSLAND PL	6-inch	cast iron	1955	5
KEYSTONE AVE	6-inch	cast iron	1950	5
MORAN ST	10-inch	steel	1917	3
WHITFIELD WAY	8-inch	cast iron	1951	3
4TH ST	4-inch	cast iron	1947	4
WASHINGTON ST	4-inch	steel	1924	3
MONROE ST	4-inch	cast iron	1928	4
STOKER AVE	6-inch	cast iron	1952	4
TOLICA ST	6-inch	steel	1947	3
WHITFIELD WAY	8-inch	steel	1949	3
WESLEY DR	6-inch	cast iron	1949	3
LODGE AVE	6-inch	cast iron	1952	10
SHANGRI-LA DR	6-inch	cast iron	1950	4
HILLSIDE DR	4-inch	cast iron	1929	5
4TH ST	6-inch	cast iron	1957	3
HASKELL ST	4-inch	cast iron	1928	3
CRANLEIGH DR	6-inch	cast iron	1951	3
E 4TH ST	8-inch	cast iron	1964	3
HUNTER LAKE DR	12-inch	steel	1954	2
HELENA AVE	8-inch	steel	1948	2

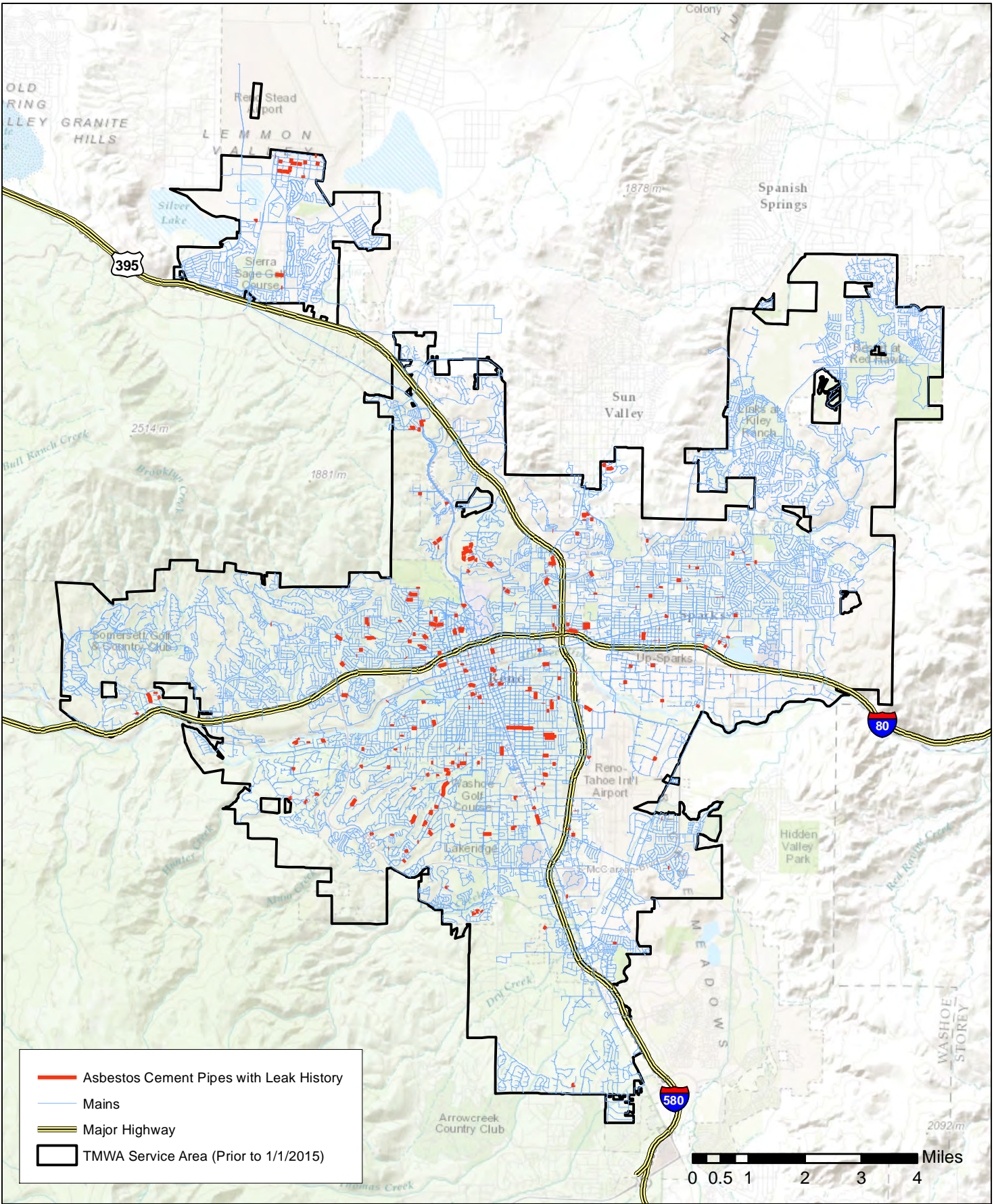
Main Location	Diameter	Material	Year Installed	Number of Leaks
HELVETIA AVE	6-inch	cast iron	1936	3
MILL ST	16-inch	MLS	1962	2
WATT ST	6-inch	steel	1947	4
ROBERTS ST	4-inch	steel	1917	2
FIELD ST	6-inch	steel	1947	2
WILLOW ST	4-inch	cast iron	1929	2
S VIRGINIA ST	4-inch	cast iron	1924	3
ROCK ALLEY	4-inch	cast iron	1930	3
N SIERRA ST	12-inch	cast iron	1949	2
EMERALD PL	6-inch	cast iron	1955	3
WILKINSON AVE	6-inch	cast iron	1950	5
N VIRGINIA ST	14-inch	steel	1959	2
WRIGHT ST	6-inch	steel	1947	2
MONROE ST	24-inch	steel	1948	2
E PRATER WAY	24-inch	coal tar steel	1978	2
CHENEY ST	4-inch	cast iron	1927	2
N CENTER ST	6-inch	steel	1919	2
COLLEGE DR	4-inch	cast iron	1927	3
ROBIN PL	4-inch	cast iron	1953	2
WESLEY DR	6-inch	cast iron	1949	2
TACOMA WAY	4-inch	cast iron	1947	2
WESTGATE RD	6-inch	steel	1947	2
W 11TH ST	6-inch	cast iron	1953	2
S MARSH AVE	6-inch	cast iron	1948	2
WRIGHT ST	6-inch	steel	1947	2
S ARLINGTON AVE	8-inch	cast iron	1932	2
TONOPAH ST	4-inch	cast iron	1928	2
SAINT LAWRENCE AVE	4-inch	cast iron	1929	2
PHILLIPS ST	6-inch	cast iron	1936	2
COLORADO RIVER BLVD	6-inch	cast iron	1946	2
MORRILL AVE	4-inch	cast iron	1929	2
WILDER ST	6-inch	cast iron	1942	2
G ST PARKING LOT	6-inch	cast iron	1952	2
HILLSIDE DR	4-inch	cast iron	1929	2
STANFORD WAY	6-inch	cast iron	1947	2
OXFORD AVE	6-inch	cast iron	1950	2
GENTRY WAY	6-inch	cast iron	1957	2
I ST	6-inch	cast iron	1950	2
MORAN ST	6-inch	cast iron	1931	2
E K ST	6-inch	cast iron	1957	2
J ST	6-inch	cast iron	1951	2
BALZAR CIR	6-inch	cast iron	1946	2
ROBIN ST	6-inch	cast iron	1951	2





<b>Main Location</b>	<b>Diameter</b>	<b>Material</b>	<b>Year Installed</b>	<b>Number of Leaks</b>
TRENTHAM WAY	6-inch	cast iron	1940	2
W PLUMB LN	24-inch	steel	1948	1
PALISADE DR	6-inch	cast iron	1951	2
CANYON DR	6-inch	cast iron	1955	2
BROWN ST	6-inch	cast iron	1949	2
MILL ST	6-inch	cast iron	1952	2
WILLOW ST	4-inch	cast iron	1927	2
CANYON DR	6-inch	cast iron	1950	2
FAIRFIELD AVE	6-inch	cast iron	1955	2
CLOUGH RD	4-inch	steel	1946	2
ROBIN ST	6-inch	cast iron	1950	2
SHARON WAY	24-inch	steel	1948	1
WALKER AVE	6-inch	cast iron	1953	2

**Appendix E**

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**Asbestos Cement Mains with Leak History**



	Asbestos Cement Pipes with Leak History
	Mains
	Major Highway
	TMWA Service Area (Prior to 1/1/2015)



**TRUCKEE MEADOWS WATER**  
AUTHORITY  
*Quality. Delivered.*

**ASBESTOS CEMENT PIPES with LEAK HISTORY**  
33% of Recorded Leaks 1989 to 2013

Truckee Meadows Water Authority  
Service Area

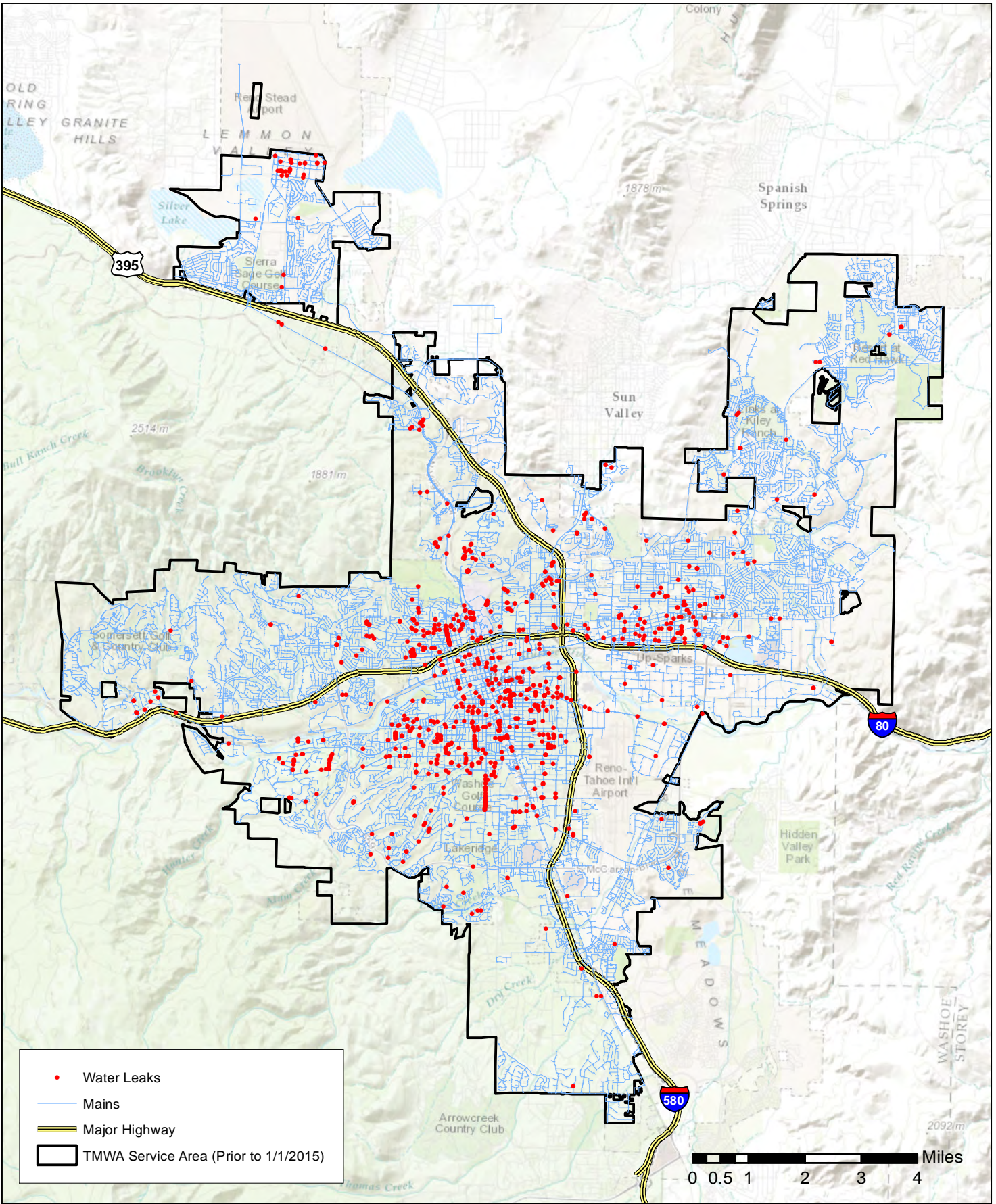
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MAP BY:	JK
REQUESTED BY:	LK
SCALE:	1 in = 2 miles



NORTH

NAD 83 NEVADA STATE  
PLANE WEST FEET





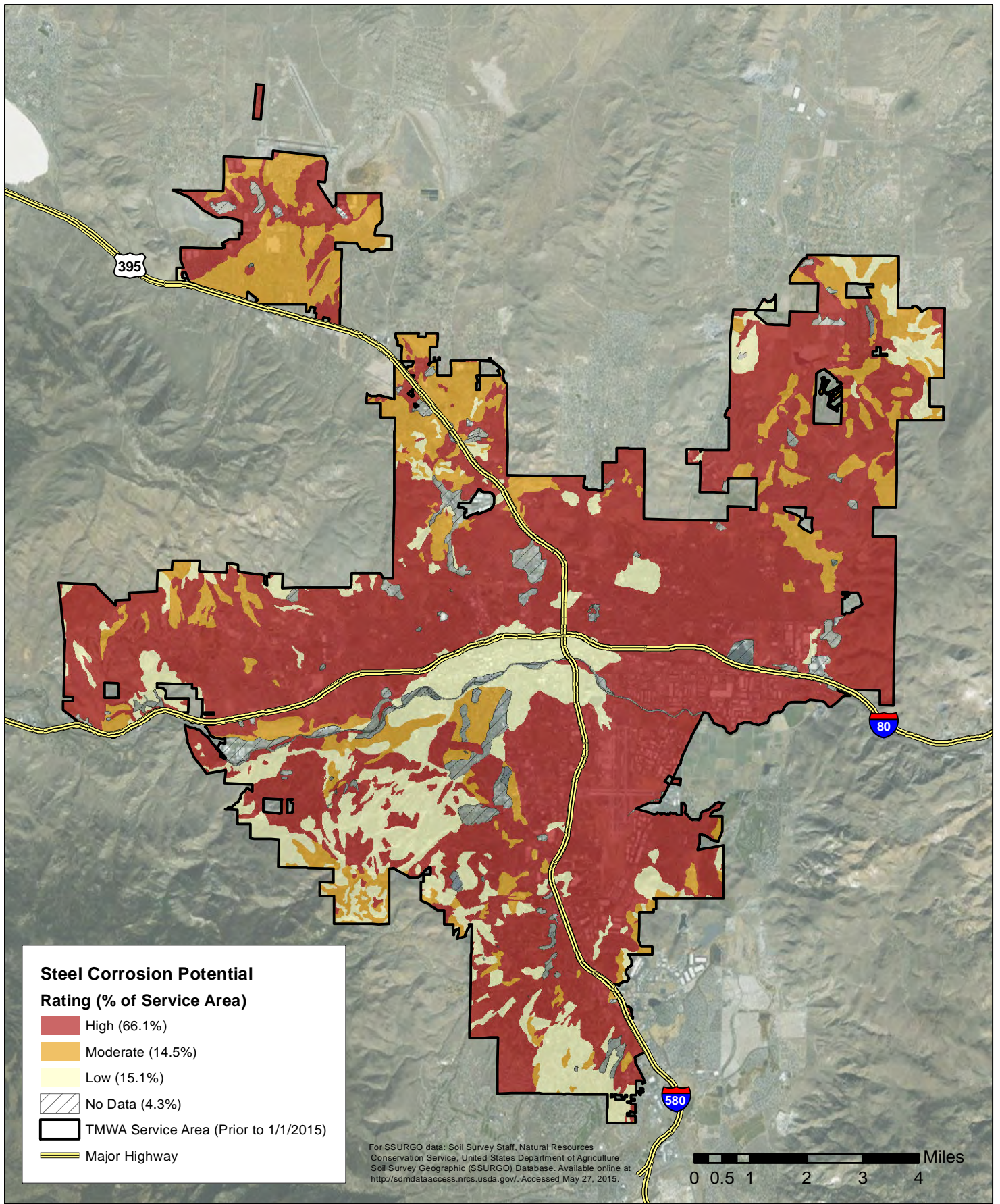
**TRUCKEE MEADOWS WATER**  
AUTHORITY  
*Quality. Delivered.*

**WATER LEAKS ON MAINS  
1989 to 2013**  
Truckee Meadows Water Authority  
Service Area

DATE	06/12/2015
MAP BY:	JK
REQUESTED BY:	LK
SCALE:	1 in = 2 miles

**NORTH**  
NAD 83 NEVADA STATE  
PLANE WEST FEET

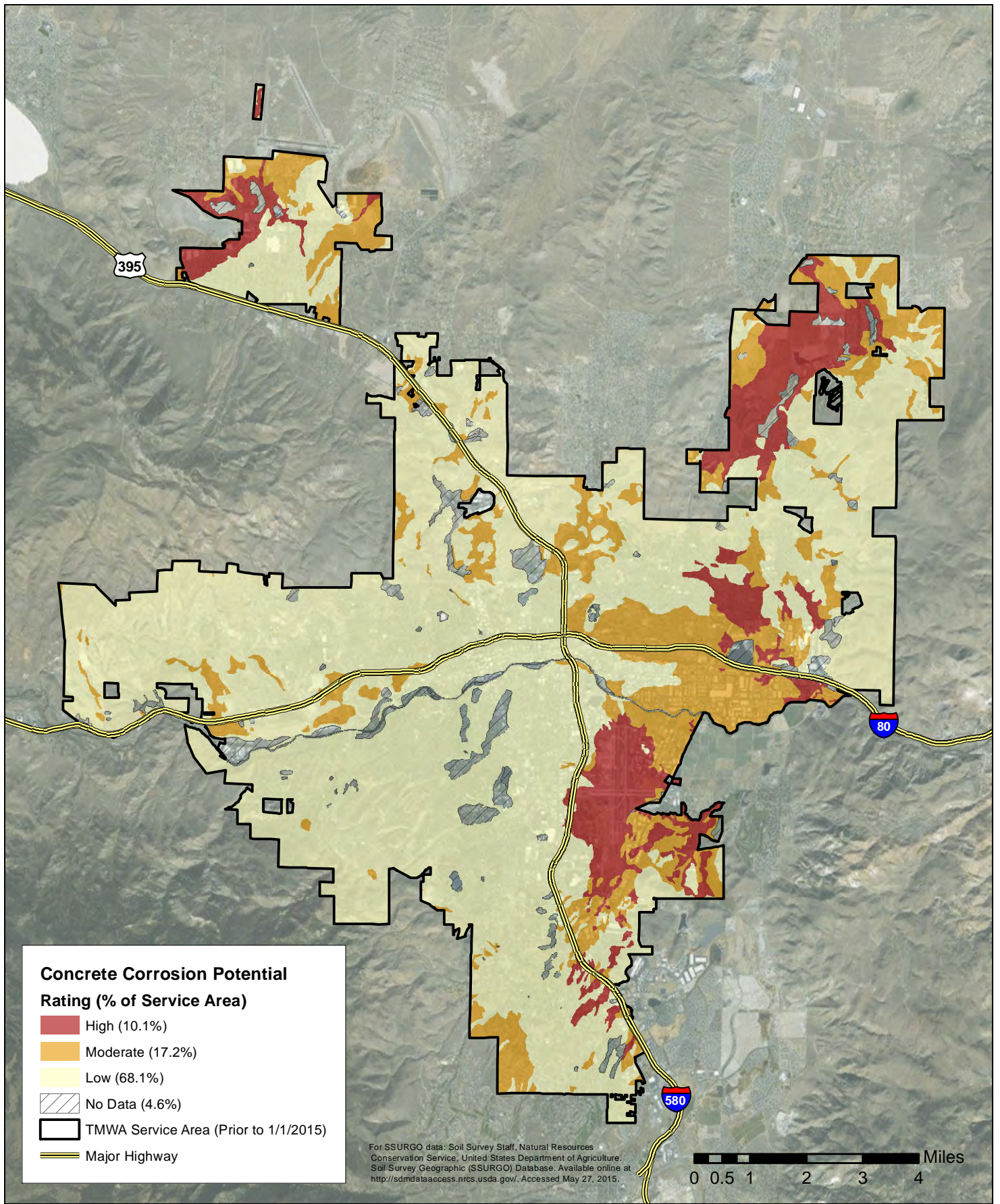




**CORROSION OF STEEL**  
Truckee Meadows Water Authority  
Service Area

DATE	05/27/2015
MAP BY:	JK
REQUESTED BY:	LK
SCALE:	1 in = 2 miles





### CORROSION OF CONCRETE

Truckee Meadows Water Authority Service Area

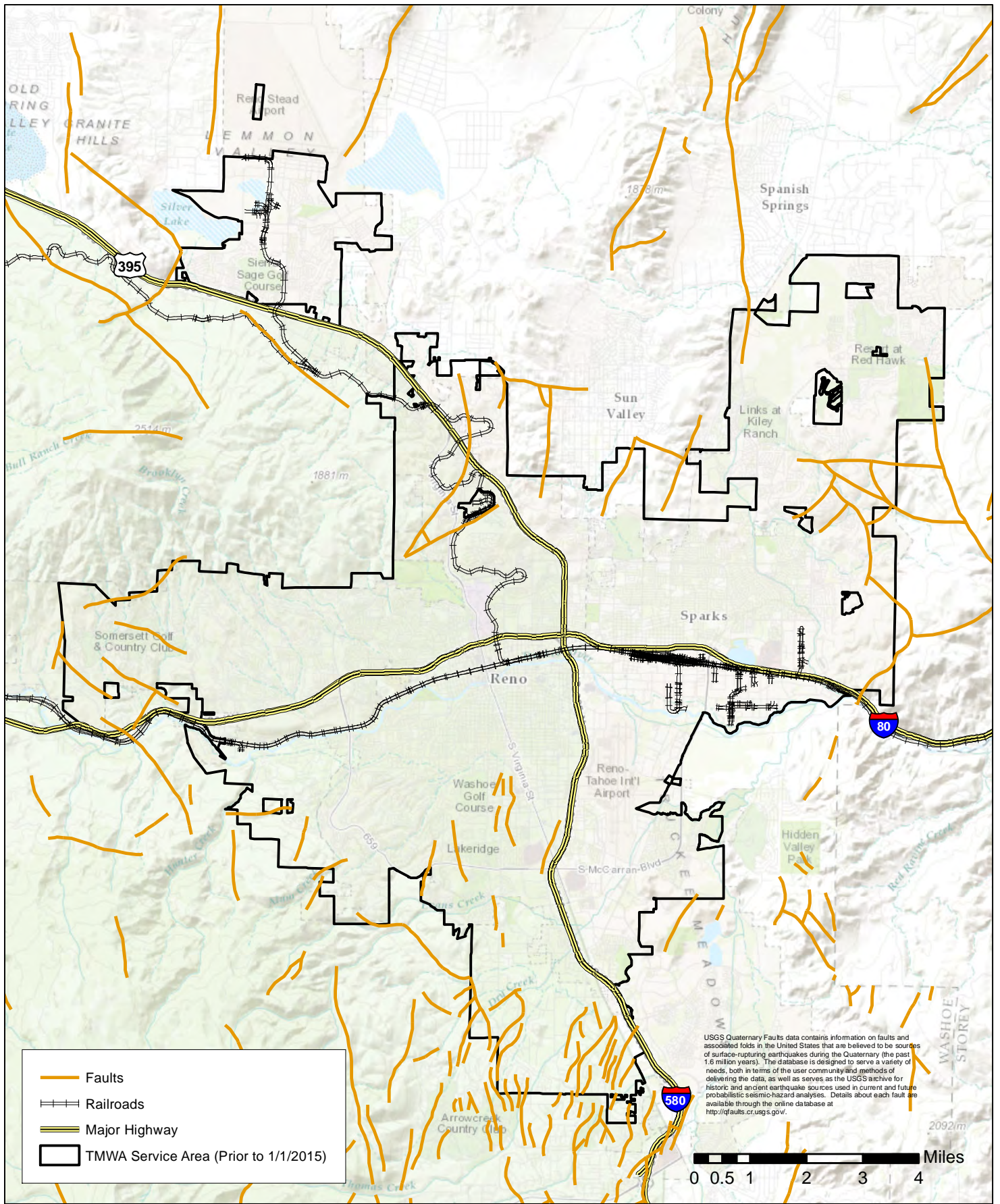
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SCALE:	1 in = 2 miles



**Appendix H**

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**Railroads and Fault Lines in the Truckee Meadows**



**RAILROADS AND FAULT LINES**  
**Truckee Meadows Water Authority**  
**Service Area**

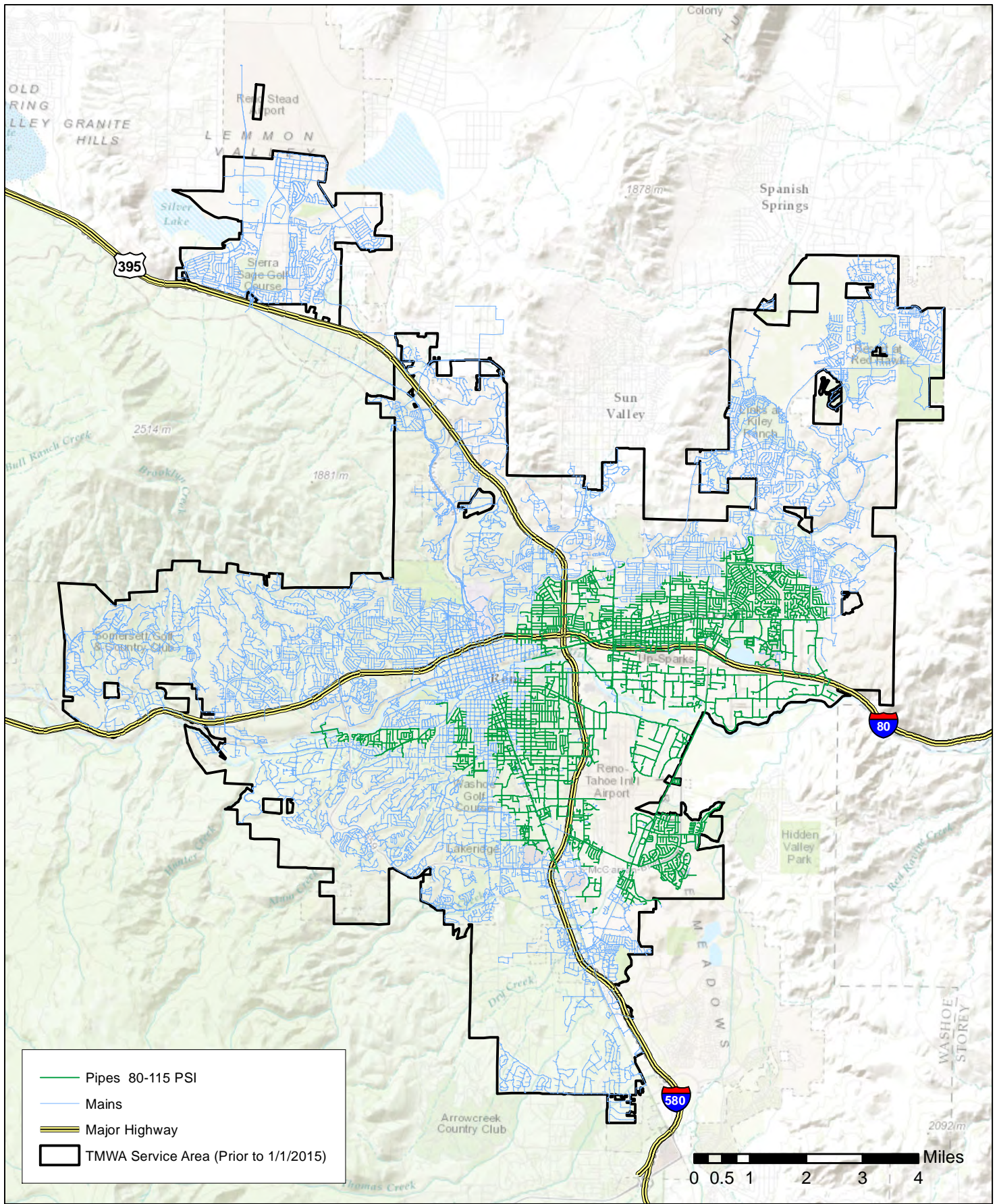
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REQUESTED BY:	LK
SCALE:	1 in = 2 miles



**Appendix I**

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**Static Pressure 80-115 psi**



**STATIC PRESSURE 80-115 PSI**

Truckee Meadows Water Authority  
Service Area

DATE 06/11/2015

MAP BY: JK

REQUESTED BY: LK

SCALE: 1 in = 2 miles



NAD 83 NEVADA STATE PLANE WEST FEET

**Appendix J**

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**Hydraulically Critical Mains**

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HOMELAND SECURITY INFORMATION

(NRS 239C.210)

**Appendix K**

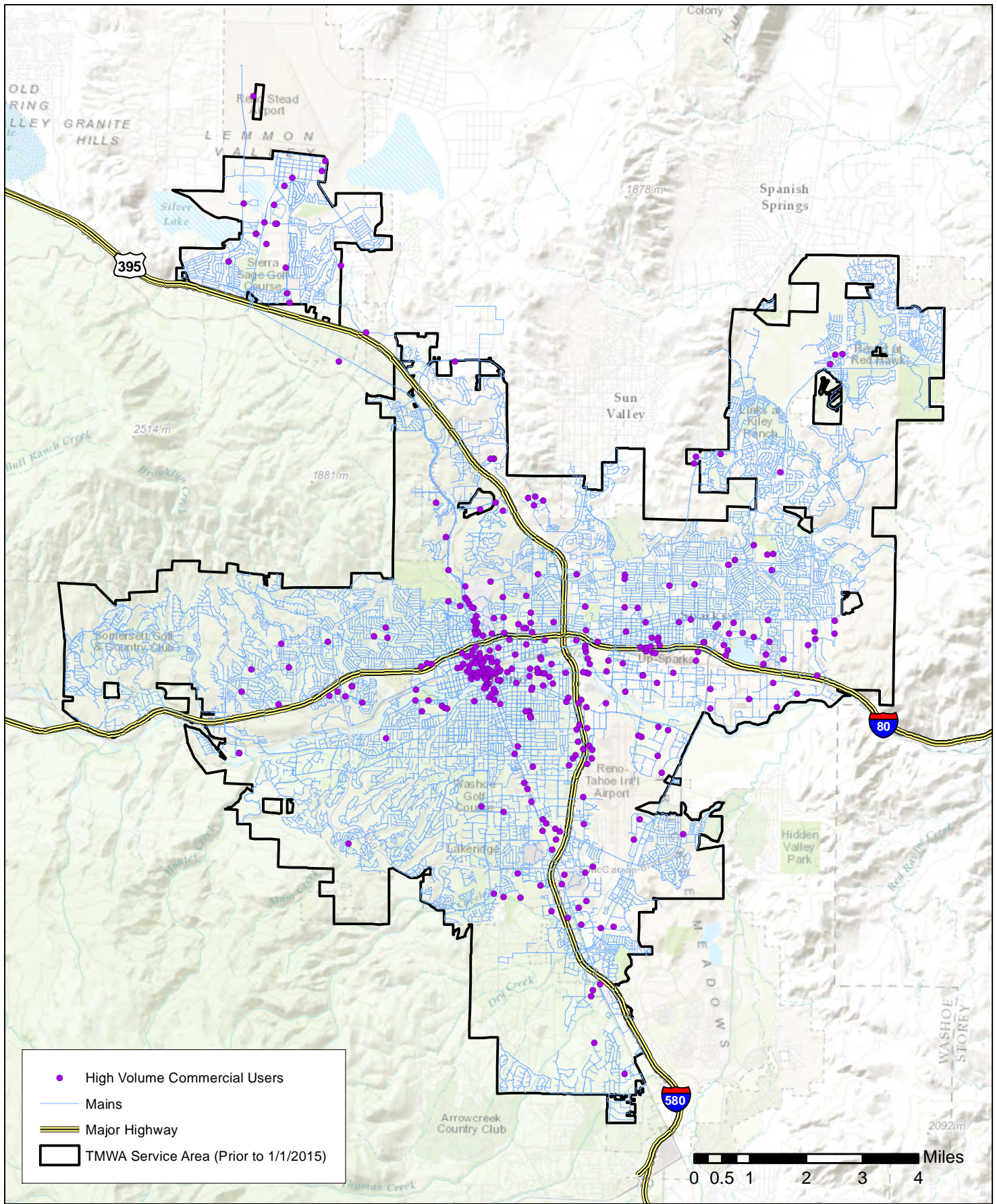
---

**High Volume Users**

PAGE REMOVED

HOMELAND SECURITY INFORMATION

(NRS 239C.210)



### HIGH VOLUME COMMERCIAL USERS

Truckee Meadows Water Authority  
Service Area

DATE	06/12/2015
MAP BY:	JK
REQUESTED BY:	LK
SCALE:	1 in = 2 miles

**NORTH**

NAD 83 NEVADA STATE PLANE WEST FEET

**Appendix L**

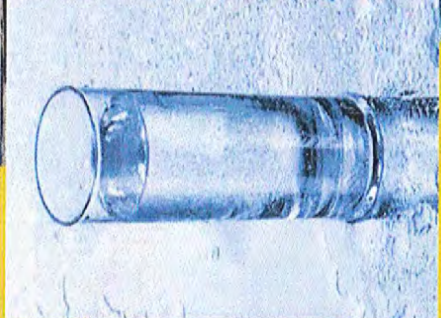
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**AWWA Buried No Longer Pipe Replacement Modeling Tool Results**

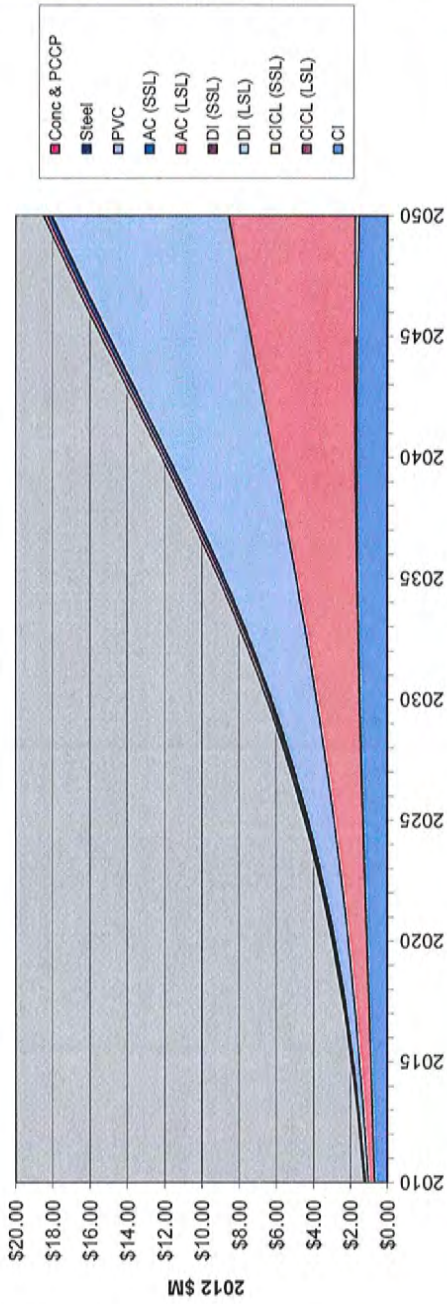
Buried No Longer™

# Pipe Replacement MODELING TOOL

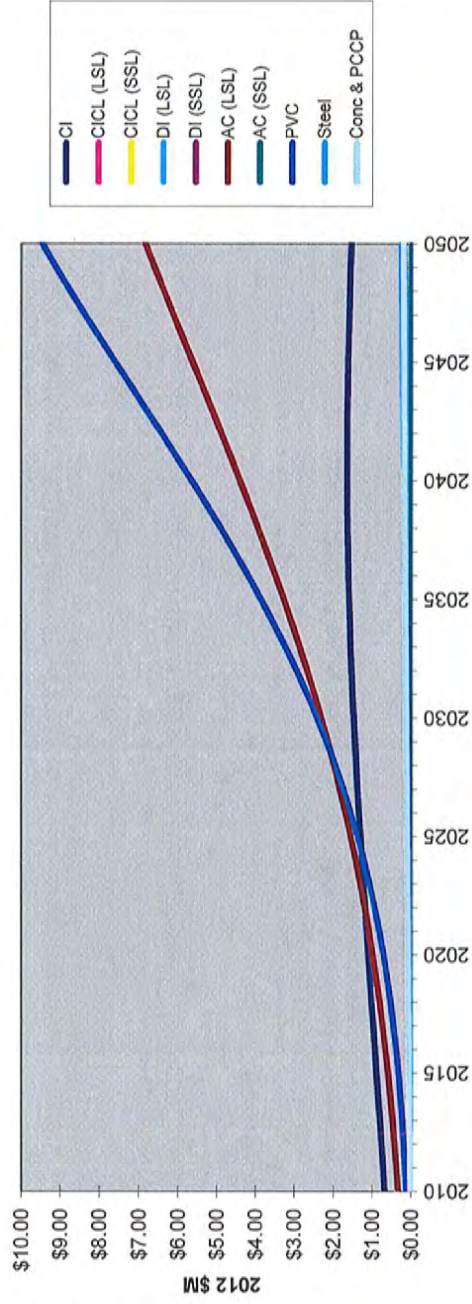
- ▶ Terms and Conditions
- ▶ User Guide
- ▶ FAQ
- ▶ Buried No Longer Report
- ▶ BNL Modeling Tool for Excel 2003
- ▶ BNL Modeling Tool for Excel 2007 or later



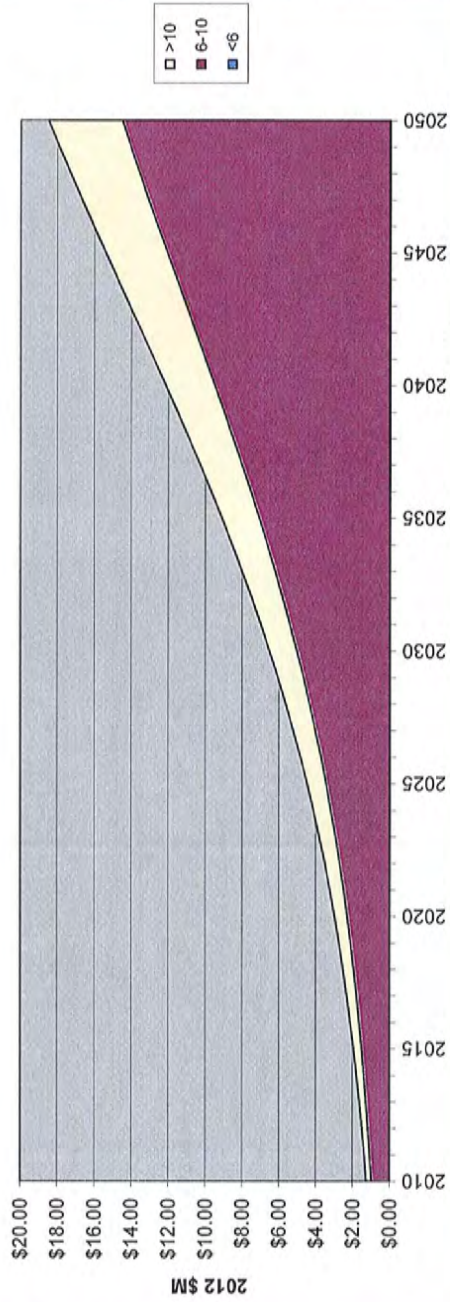
Estimated Replacement Expenditure by Pipe Material



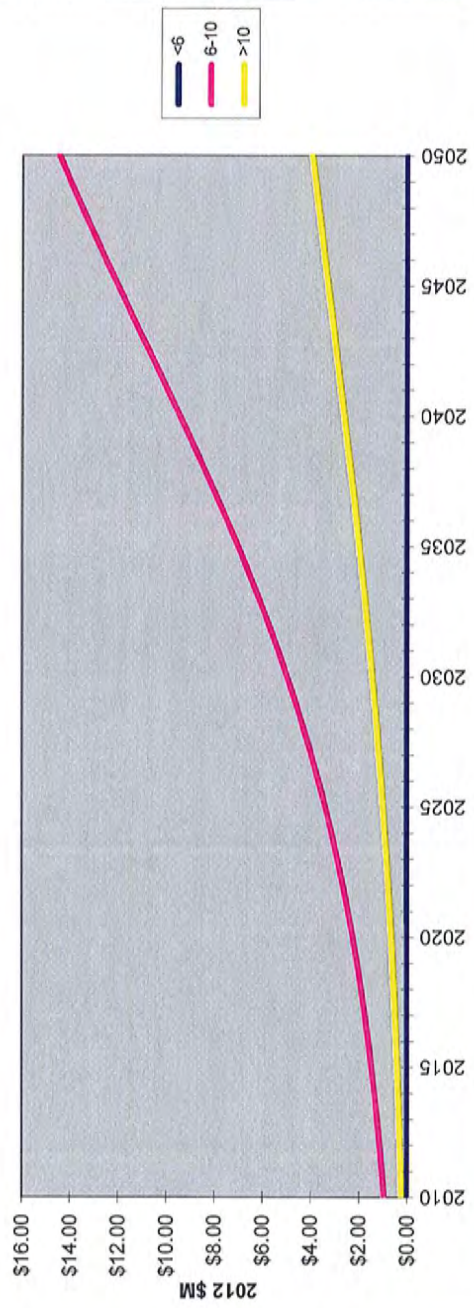
Estimated Replacement Expenditure by Pipe Material: Comparative



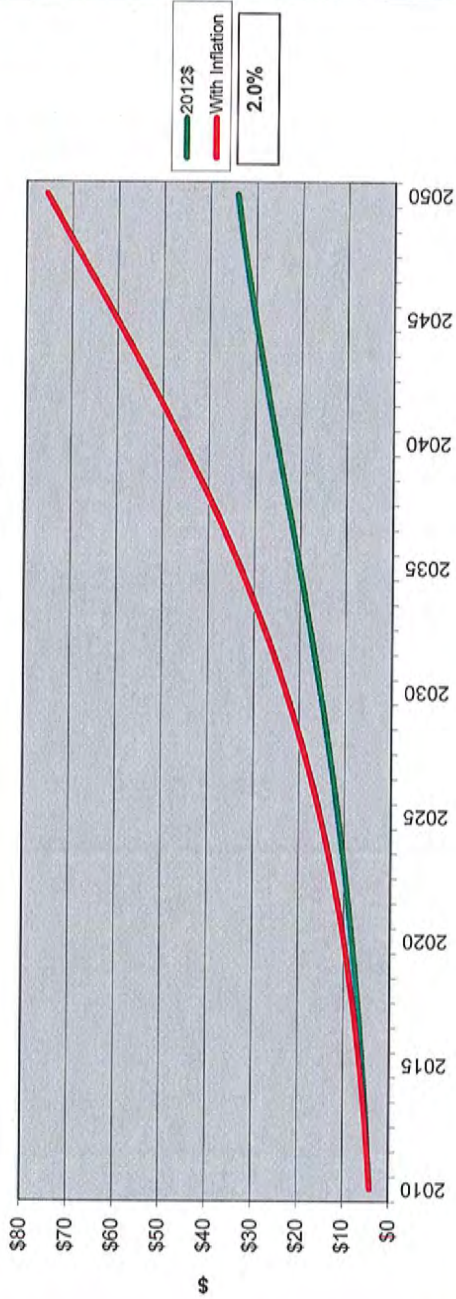
Estimated Replacement Expenditure by Pipe Size Category



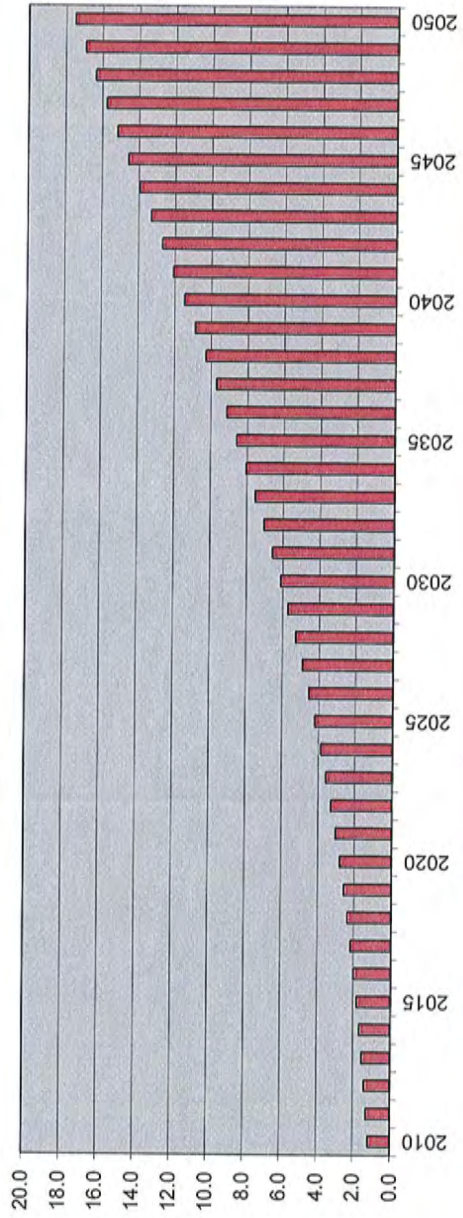
Estimated Replacement Expenditure by Pipe Size Category: Comparative



Estimated Replacement Expenditure per Capita of Population Served



Estimated Replacement in Miles per Year



## Pipe Replacement Base Case Input Reference Panel

Mains Network Factors		1920	Commencement Year	Ref. Model Types	Nominated System %
Ref. #		Ref. #	Pipe Material/Size		
1	CI <6	✓		✓	0.0%
2	CI 6-10	✓		✓	6.6%
3	CI >10	✓		✓	0.0%
4	CICL (LSL) < 6	✓		✓	0.0%
5	CICL (LSL) 6-10	✓		✓	0.0%
6	CICL (LSL) >10	✓		✓	0.0%
7	CICL (SSL) < 6	✓		✓	0.0%
8	CICL (SSL) 6-10	✓		✓	0.0%
9	CICL (SSL) >10	✓		✓	0.0%
10	DI (LSL) < 6	✓		✓	0.0%
11	DI (LSL) 6-10	✓		✓	0.0%
12	DI (LSL) >10	✓		✓	5.0%
13	DI (SSL) < 6	✓		✓	4.0%
14	DI (SSL) 6-10	✓		✓	0.0%
15	AC (LSL) < 6	✓		✓	0.0%
16	AC (LSL) 6-10	✓		✓	20.0%
17	AC (LSL) >10	✓		✓	18.7%
18	AC (SSL) < 6	✓		✓	0.0%
19	AC (SSL) 6-10	✓		✓	0.0%
20	PVC < 6	✓		✓	0.0%
21	PVC 6-10	✓		✓	40.0%
22	Steel 6-10	✓		✓	3.0%
23	Steel >10	✓		✓	1.7%
24	Conc & PCCP 6-10	✓		✓	0.0%
25	Conc & PCCP >10	✓		✓	1.0%
			<b>TOTAL</b>		<b>100.0%</b>
<b>Population Served Adjustment</b>					
300,000	Nominated 2010 Population				
2.00%	Nominated Population Growth Factor (% of 2010) [Default = N/A]				
<b>Cost Adjustment Factors</b>					
2.00%	Estimated Annual Rate of Inflation (%)				
\$175	Local Cost/Linear Foot of 8" (\$)				
1,340	Local System Length (Miles)				
<b>Key Outputs for Population of</b>					
J	Reference Model				<b>300,000</b>

# Glossary

Region/System Size	Code
Northeast Large	A
Northeast Medium & Small	B
Northeast Very Small	C
Midwest Large	D
Midwest Medium & Small	E
Midwest Very Small	F
South Large	G
South Medium & Small	H
South Very Small	I
West Large	J
West Medium & Small	K
West Very Small	L

System Size Category	Population
Large	> 50,000
Medium	10,000 – 50,000
Small	3,300 – 9,999
Very Small	< 3,300

Pipe Descriptions	
AC	Asbestos Cement
CI	Cast Iron
CICL	Cast Iron Concrete Lined
Conc.	Concrete (incl. Reinforced)
DI	Ductile Iron
PCCP	Prestressed Concrete Cylinder Pipe
PVC	Polyvinyl Chloride*
LSL	Long Service Life (Benign operating conditions and/or enhanced laying practices.)
SSL	Short Service Life (Aggressive operating conditions and/or early laying practices.)
Steel	Steel

\*Note "PVC" used as a 'catch-all' for later pipe types such as Glass Reinforced Plastic (GRP) and High Density Polyethylene (HDPE) which are not expected to impact significantly on replacement in the modeling period.

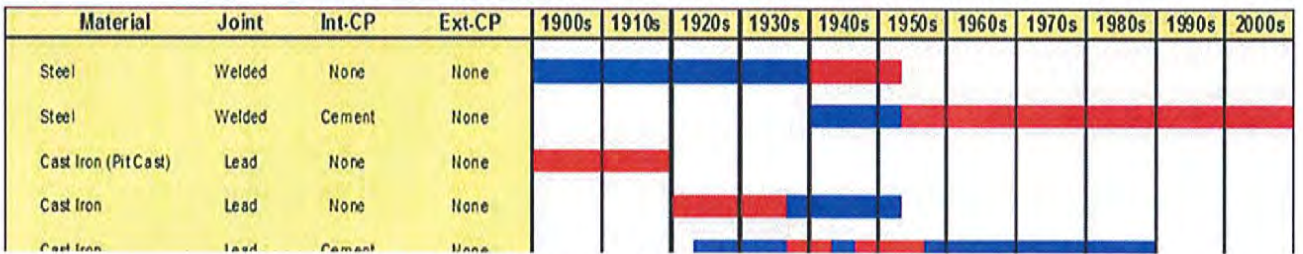
### The Charts

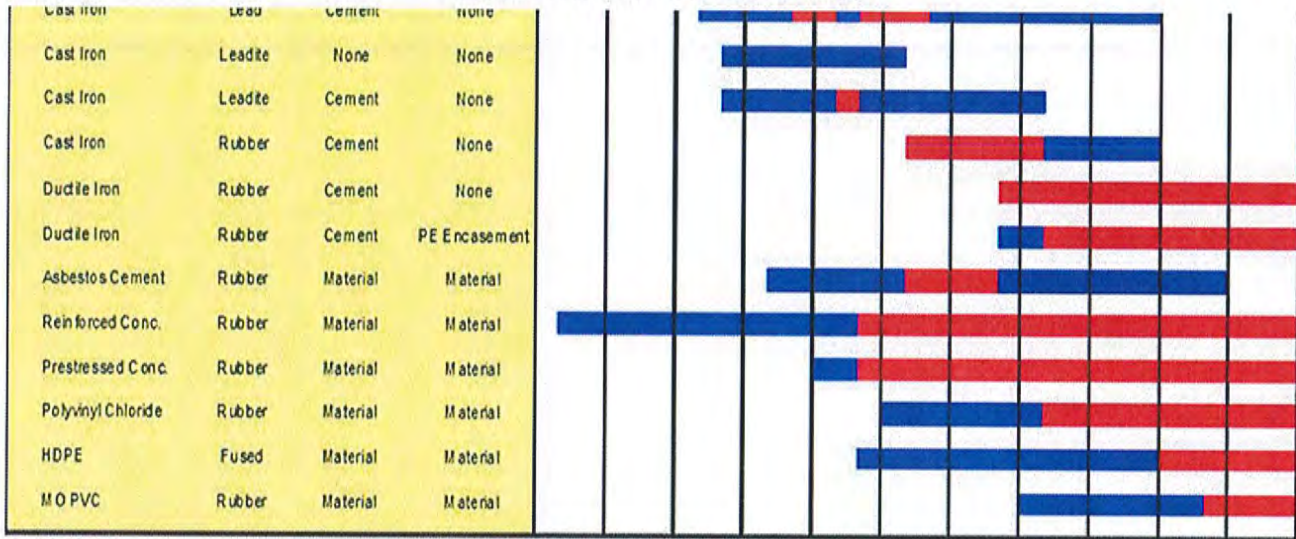
**Base Case Review Set**  
The Base Case outcomes illustrate the predicted levels of expenditure required to meet replacement requirements if current utility practices for main replacement are maintained.

**Deferral Review Set**  
The Deferral outcomes illustrate what impact a deferral of a portion of the expenditure (possibly due to financial constraints) would have, with due regard to a subsequent 'catch-up' period for the water mains replacement program.

- 1. Estimated Replacement Expenditure by Pipe Material**  
This stacked chart shows the total expenditure expected each year of the modeling period (in constant 2012 \$s) subdivided into the expected contribution by each pipe type.
- 2. Estimated Replacement Expenditure by Pipe Material: Comparative**  
This chart shows the same information with respect to the projected expenditure for each pipe type as shown in '1' above, but each pipe type is plotted individually.
- 3. Estimated Replacement Expenditure by Pipe Size Category**  
As per '1' above but subdivided in terms of pipe size categories.
- 4. Estimated Replacement Expenditure by Pipe Size Category: Comparative**  
This chart shows the same information with respect to the projected expenditure for each pipe size category as shown in '3' above, but each pipe category is plotted individually.
- 5. Estimated Replacement Expenditure per Head of Population Served**  
This chart shows expected per capita expenditure on replacement based on the population served; it should not be interpreted as a direct proxy for changes in household bills, as commercial and industrial sector customers are not taken into account. The expected outcome is presented both in terms of constant 2010 dollars (as is the case for chart types 1–4 above) and what the actual cost would be in each individual year assuming an average annual inflation rate (selected by the user in the "Input" Tab).
- 6. Estimated Replacement in Miles per Year**  
Quantifies the expected asset replacement challenge in terms of miles of pipe to be replaced.

### Pipe-Material Installation Eras





Commercially Available  
Predominately in Use

**Derived Current Service Lives for Installed Mains**

Pipe life estimates are based on pipe quality and maintenance practices between 1870 and 1970, not those of pipes purchased and installed today.

Derived Current Service Lives (Years)	CI	CI (LSL)	CI (SSL)	DI (LSL)	DI (SSL)	AC (LSL)	AC (SSL)	PVC	Steel	Conc & PCCP
Northeast Large	130	120	100	110	50	80	80	100	100	100
Midwest Large	125	120	85	110	50	100	85	55	80	105
South Large	110	100	100	105	55	100	80	55	70	105
West Large	115	100	75	110	60	105	75	70	95	75
Northeast Medium & Small	115	120	100	110	55	100	85	100	100	100
Midwest Medium & Small	125	120	85	110	50	70	70	55	80	105
South Medium & Small	105	100	100	105	55	100	80	55	70	105
West Medium & Small	105	100	75	110	60	105	75	70	95	75
Northeast Very Small	115	120	100	120	60	100	85	100	100	100
Midwest Very Small	135	120	85	110	60	80	75	55	80	105
South Very Small	130	110	100	105	55	100	80	55	70	105
West Very Small	130	100	75	110	60	105	65	70	95	75

LSL indicates a relatively long service life for the material resulting from some combination of benign ground conditions and evolved laying practices etc.  
SSL indicates a relatively short service life for the material resulting from some combination of harsh ground conditions and early laying practices, etc.

## **APPENDIX 5-2**

Free to Choose:  
Promoting Conservation by Relaxing Outdoor  
Watering Restrictions





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## Free to choose: Promoting conservation by relaxing outdoor watering restrictions

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### ABSTRACT

Many water utilities use outdoor watering restrictions based on assigned weekly watering days to promote conservation and delay costly capacity expansions. We find that such policies can lead to unintended consequences – customers who adhere to the prescribed schedule use more water than those following a more flexible irrigation pattern. For our application to residential watering in a high-desert environment, this “rigidity penalty” is robust to an exogenous policy change that allowed an additional watering day per week. Our findings contribute to the growing literature on leakage effects of regulatory policies. In our case inefficiencies arise as policies limit the extent to which agents can temporarily re-allocate actions.

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## 1. Introduction

Water consumption across the globe has tripled in the last 50 years, and is expected to continue to rise rapidly. Water scarcity is expected to be further exacerbated by global warming via prolonged droughts and increasing system losses (Cromwell et al., 2007). The United Nations predicts that by 2030 almost half of the world's population will be living in areas of high water stress (World Water Assessment Programme, 2009) and nearly every region in the United States has experienced drought induced water shortages over the last five to ten years (Environmental Protection Agency, 2008). The sustainable provision of water is thus one of the most critical challenges facing policy-makers in both the U.S. and world at

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<sup>1</sup> Part of this research was conducted while Moeltner was a Visiting Scholar at the Luskin Center for Innovation, School of Public Affairs, University of California, Los Angeles.

large. Residential households consume close to two thirds of all publicly supplied water in the United States ([Environmental Protection Agency, 2002](#)). On average, approximately 15% of residential use is allocated to landscape and lawn irrigation. However, in the arid west and south this proportion can be as large as 30–35%. In total, an estimated seven billion gallons of publicly provided water are allocated for this purpose daily ([Environmental Protection Agency, 2008, 2008](#)). Policy makers and water utilities have thus directed considerable efforts to the management of residential outdoor irrigation. In most cases these efforts focus on outdoor watering restrictions (OWRs) that limit the timing, length, and frequency of sprinkler use.<sup>2</sup>

Such OWRs have been implemented in many areas within and outside the United States. As noted in [Table A.9 in Appendix A](#), most of these regimes limit weekly watering to between one and three assigned days determined by street address. Moreover, most of these regimes (see, e.g., San Antonio or the State of Georgia) follow a paradigm whereby the number of assigned days is reduced under progressively severe drought conditions.

To date, economists have primarily focused on two aspects of OWR policies: (i) the overall impact on water demand, and (ii) the welfare effects for residential consumers. For example, [Shaw and Maidment \(1987\)](#) find that a one-per-five days watering restriction reduced overall demand by 3–5% during the 1984–1985 drought years in Austin, Texas. [Renwick and Green \(2000\)](#) examine monthly consumption for eight California water utilities during the 1985–1992 drought period and find that OWRs of a general nature generated an approximate 30% reduction in use. The second set of studies focus on welfare implications of OWRs and other drought-related water use restrictions. Typically, these studies employ non-market valuation techniques to elicit households' willingness-to-pay (WTP) to avoid such restrictions ([Griffin and Mjelde, 2000](#); [Hensher et al., 2006](#)), or an increased risk of future restrictions ([Howe and Smith, 1994](#); [Griffin and Mjelde, 2000](#)).

Despite the growing importance of OWRs as a Demand-Side Management (DSM) intervention, surprisingly little is known about the relative performance of different OWR implementation strategies. Given that OWRs vary substantially across communities, such omission is particularly noteworthy. This study seeks to fill this gap in the literature. We examine daily consumption data for thousands of customers in the Reno/Sparks area of Northern Nevada during the 2008 and 2010 summer months. This temporal break affords a unique opportunity to examine an exogenous policy change in OWRs that allowed households an added assigned watering day each week during the 2010 watering season.

Our analysis uncovers an unintended consequence associated with the use of assigned watering schedules – weekly water use and peaks are significantly higher during weeks that include all officially assigned watering days compared to weeks with an equal number of watering days but a more flexible pattern of use. These “rigidity penalties” are substantial, amounting to 20–25% of weekly consumption and 30–40% of weekly peaks for the typical customer. Although the 2010 policy change had a noticeable impact on daily peaks, it had no discernible effect on weekly consumption of the associated “rigidity penalties”.

Viewed in its totality, our data call into question the efficacy of OWRs that limit watering to assigned days. In this regard, our analysis extends prior work exploring the unintended consequences of policy actions that either introduce heterogeneity in standards across factories or regions ([Felder and Rutherford, 1993](#); [Fowlie, 2009](#)) or nested state and federal regulation ([McGuinness and Ellermann, 2008](#); [Goulder and Stavins, 2011](#); [Goulder et al., 2012](#)).<sup>3</sup> Whereas the cited work focuses on leakages that arise through the spatial reallocation of actions, our paper highlights that a similar phenomena can arise if policies limit the extent to which agents can *temporally* reallocate actions. In our setting, adherence to the official water schedule requires households to ignore time-varying conditions such as high wind events that reduce the efficiency of irrigation systems.

## 2. Empirical background and data

Water provision in the Reno/Sparks urban area is managed by the Truckee Meadows Water Authority (TMWA), a non-profit, community-owned public utility. TMWA first implemented OWRs in 1992 in reaction to a prolonged drought. They became permanent in 1996 to guard against future droughts and assure adequate flows of the Truckee River. The watering regulations allow sprinkler use during the morning and evening of assigned days determined by the last digit of a resident's address.<sup>4</sup> Prior to 2010, the policy allowed households two assigned watering days per week. During the 2010 watering season, the OWR was relaxed and allowed a third weekly watering day. These OWRs are only mildly enforced with infrequent water patrols and nominal fines (up to \$75) for repeated violations in the same calendar year.

In 2008 TMWA initiated the collection of daily water consumption data for a large, representative sample of customers. Meter readings were obtained via nightly drive-by's using remote sensing devices. Two teams of readers covered the same

<sup>2</sup> Given the price inelastic nature of water demand, such regulatory interventions are more effective means to influence consumption than price-based policies ([Renwick and Green, 2000](#); [Mansur and Olmstead, 2007](#); [Olmstead et al., 2007](#); [Worthington and Hoffman, 2008](#)). Furthermore, there are generally fewer equity concerns and less political resistance to OWRs than to price-based policies ([Renwick and Archibald, 1998](#); [Timmins, 2003](#); [Brennan et al., 2007](#)).

<sup>3</sup> Unintended consequences have also been documented in a number of other settings. For example, [Davis and Kahn \(2010\)](#) show that while trade in used vehicles between Mexico and the United States following the passage of NAFTA lowers average vehicle emissions per mile in both countries, aggregate greenhouse gas emissions rise due to lower retirement rates of used cars in Mexico. [Bento et al. \(2011\)](#) show how policy changes in California that allowed single-occupancy, ultra-low emission vehicles access to HOV lanes significantly increased travel times for carpoolers and had no impact on travel times for those in non-HOV lanes.

<sup>4</sup> There are no restrictions on watering via *hand-held* hoses.

**Table 1**  
 Sample sizes for 2008 and 2010.

Intact weeks	2008				2010			
	HHs	%	obs	%	HHs	%	obs	%
5	3567	40.8	17,835	33.9	2084	27.2	10,420	21.5
6	2284	26.1	13,704	26.0	826	10.8	4956	10.2
7	2041	23.3	14,287	27.1	4739	61.9	33,173	68.3
8	855	9.8	6840	13.0	3	0.0	24	0.0
Total	8747	100.0	52,666	100.0	7652	100.0	48,573	100.0

Intact weeks	Overlap <sup>a</sup> , 2008				Overlap, 2010			
	HHs	%	obs	%	HHs	%	obs	%
5	679	38.4	3395	31.6	1061	60.1	5305	52.4
6	435	24.6	2610	24.3	121	6.9	726	7.2
7	463	26.2	3241	30.1	584	33.1	4088	40.4
8	189	10.7	1512	14.1	0	0.0	0	0.0
Total	1766	100.0	10,758	100.0	1766	100.0	10,119	100.0

<sup>a</sup> “Overlap” comprises households sampled in both 2008 and 2010.

route for 63 consecutive days between June 22 and August 23, 2008.<sup>5</sup> The same exercise was repeated between June 20 and August 21, 2010 although the routes differed somewhat from the 2008 itineraries due to construction activities.<sup>6</sup>

Overall, we observe approximately 1.9 million daily meter readings from approximately 20,000 unique residential customers. In preparing the final data set, we eliminate premises with ownership changes or multiple ownerships during a given year’s research period. We further drop households with a total of 14 or more readings of zero consumption and customers with four or more consecutive zero readings anywhere in the daily series to lower the risk of including non-permanent residences and vacation homes. These cleaning steps truncated the set of eligible residents by approximately 15% for each year.

Given our focus on weekly watering frequencies, only weeks for which we obtain a full set of readings for a given household are usable. Further, to identify a household’s watering days and weekly watering patterns, a minimum number of intact weeks (MIW) was required. Yet, to maximize the number of residents present in both sample periods, we had to consider the relationship between the stringency of our MIW criterion and the size of our overlap sample. In balancing these requirements we settle for an MIW threshold of five full weeks of daily readings. After eliminating a few isolated cases with obvious water leaks or missing information on basic building characteristics we generate a final sample that includes 52,666 weekly observations from 8747 residents for 2008 and 48,573 observations from 7652 unique residents for 2010. Of these households, 1766 appear in both the 2008 and 2010 samples and comprise our “overlap” sample. Table 1 shows the distribution of intact weeks for both the full and overlap samples by year.

The top half of Table 2 depicts basic household characteristics for the two full samples. The 2010 sample comprises, on average, slightly smaller and older properties. There is also a 44% decline in average tax-assessed property value from 2008 to 2010 reflecting the severe economic downturn in Nevada over the sample period.

We combine our household data with the following basic climate indicators: average, minimum, and maximum daily temperature (in degF), average wind speed (over 24 hourly measurements, in knots), and maximum sustained wind speed (in knots, measured for ten minutes every hour). As is common in arid high-desert climates, there were no noteworthy rainfall events during our sampling periods. Climate statistics are shown in the bottom half of Table 2. Although the summer of 2010 was slightly cooler than the summer of 2008, the wind statistics are very similar for the two sampling periods.

### 3. Identification of policy effects

#### 3.1. Definition of treatments

We aim at identifying the impact of two design features of the Truckee Meadows OWRs on weekly water use and peak (maximum daily consumption in a given week)<sup>7</sup>: (i) the total number of permissible watering days per week and (ii) the

<sup>5</sup> The readings were obtained between the hours of 9pm and 3am. According to TMWA, the vast majority of households complete watering by 9pm.

<sup>6</sup> Drivers were instructed to proceed no slower than the posted speed limit to assure adequate spatial coverage. While this resulted in a large number of customers being included in the sample, it also generated some missing readings due to parked vehicles or other obstacles preventing a clean line-of-sight. Therefore, a completely uninterrupted series of readings is available only for a small subset of the sample.

<sup>7</sup> System-wide consumption peaks are important to utilities as they are closely related to the cost of water provision. Specifically, lower peak demand can be satisfied via stored water, distributed by gravity. Storage units can then be replenished at night at lower pumping costs. In contrast, high peak use

**Table 2**  
 Household and climate characteristics.

	2008				2010			
	Mean	Std.	Min.	Max.	Mean	Std.	Min.	Max.
Age	20.9	17.6	1.0	104.0	23.1	16.4	2.0	106.0
Lot size (1000 sqft)	10.1	7.0	0.0	49.7	7.6	3.3	0.0	48.8
Sqft (1000s)	2.0	0.8	0.5	15.2	1.8	0.6	0.5	7.7
Value (\$10,000s)	270.5	160.2	69.4	2637.4	150.7	65.6	33.8	762.8
Fixtures	12.0	3.4	0.0	64.0	11.1	2.8	0.0	27.0
Bedrms	3.3	0.9	0.0	23.0	3.2	0.7	0.0	8.0
Bathrms.	2.4	0.7	0.0	16.0	2.2	0.6	0.0	6.0
Avg. temp (F)	77.9	3.3	69.4	84.2	75.8	4.7	61.7	85.4
Min. temp	59.9	3.5	53.1	66.0	58.9	4.8	44.6	69.1
Max. temp	95.7	3.0	89.1	102.0	92.8	5.2	78.8	102.2
Avg. wind (knots)	5.2	1.4	2.8	9.3	5.7	1.3	2.5	8.3
Max. wind	16.2	4.2	7.0	29.9	16.8	4.2	8.9	32.1
Max. gust	23.3	4.1	15.0	30.9	24.5	5.0	14.0	37.9

“pinning” of the allowable number of days to specific days of the week (say, Wednesday, Saturday), versus letting households choose their watering days in a more flexible fashion.

For the former objective, we hypothesize that granting more watering days will induce a more even distribution of weekly irrigation, and thus reduce weekly peaks for the typical household. In addition, this smoother distribution, by reducing the gap between permitted days, may curb losses due to runoff and evaporation, as households are less likely to over-soak their lawn on assigned days.

For the latter objective, we separate weekly watering patterns into three categories: (i) “Schedule” (*S*), (ii) “Schedule-plus” (*SP*), and (iii) “Off-schedule” (*OS*). The first group comprises weeks with watering patterns that correspond *exactly* to the assigned TMWA schedule. The second category describes weeks that include *all assigned days*, plus some additional (“illegal”) days of outdoor use. The third group exhibits the most varied weekly watering patterns, with the common feature of *non-watering* on at least one of the assigned days. For ease of exposition we will at times combine the first two groups under the heading “Schedule-based” (*SB*). Thus,  $S \cup SP = SB$ , and  $SB \cup OS =$  entire sample. This centers the analytical focus squarely on the degree to which the official schedule influences or “guides” irrigation patterns.

We hypothesize that *S* types are nudged inadvertently towards wasteful behavior for two main reasons: First, they face the “large gaps” problem mentioned above, which can lead to over-watering and corresponding losses to runoff and evaporation. Second, adherence to the official schedule requires that such households ignore time-varying natural conditions such as (common) high wind events that can further exacerbate irrigation inefficiency. Both effects are likely to increase weekly consumption and, especially, weekly peaks.

In comparison, *SP* types may be less prone to over-watering, as they distribute weekly irrigation over more-than-permitted days, but may still experience wind losses in their persistence to incorporate the assigned days. In contrast, we surmise that *OS* types pay the least attention to the official schedule, and more attention to their yard’s actual water needs and/or random fluctuations in weather conditions. This makes them the most disobedient, but perhaps also the most efficient TMWA customers.

In summary, we set forth to explore whether compliance with Reno’s OWR policy introduces unintended consequences that compromise conservation aims. We will henceforth refer to water losses induced by the day-of-week assignment as “rigidity effect”.

### 3.2. Identification strategy

We have exogenous variation in the number of permitted watering days – the policy change from two to three assigned days between 2008 and 2010. Ideally, we would have also been able to exogenously randomize the flexibility with which a household can allocate these days over the course of a week, i.e. assignment to *S*, *SP*, and *OS* categories. Unfortunately, such exogenous policy variation did not occur during our research period.

Instead, we rely upon an alternate strategy for identification – other exogenous shocks that sort a given household into one type or other in a given week. Conditional on the existence of such shocks we can then exploit both cross-sectional and within household variation in weekly watering patterns to estimate the rigidity effect. This is because there are relatively few customers that follow the same weekly irrigation strategy (*S*, *SP*, or *OS*) for the entire observation period. Most households display a mixed pattern of weekly irrigation, both in terms of frequency and timing. Therefore, identification can draw on both within and between household variation.

forces daytime pumping, when electricity costs are highest. If this occurs frequently, the utility may have to undergo costly capacity expansions for water storage. Therefore, a utility generally tries to implement water use policies that reduce daily peaks at the household level.

The challenge at hand is thus to (i) identify plausible exogenous drivers that induce customers to change watering patterns, and (ii) convincingly rule out confounding effects that could drive both weekly watering patterns and outcomes of interest, i.e. weekly use and peak.

With respect to exogenous factors we provide some evidence in the empirical section that *SB* versus *OS* choices are likely driven by randomly fluctuating daily wind patterns. Specifically, a given household may want to avoid wind-induced water losses – a common problem in this rain shadow/foothill location – by transferring watering events from a windy day to the next calm day. For the Reno/Sparks case this usually means foregoing the evening application and instead watering on the next (potentially unassigned) day. *Inter*-household differences in “wind awareness” or ability to flexibly manipulate irrigation systems then drives much of the observed cross-household variation in adherence to the official schedule. Naturally, some customers may also be intrinsically more reluctant to break the official rules, and may require “stronger wind shocks” to transfer watering to an off-day. This would add additional cross-sectional variation in observed behavior.

In addition, there may be *intra*-household, time-varying differences in the daily ability to react to the threat of irrigation losses due to wind. For example, the entire household or the person in charge of the irrigation system may not be at home or unavailable on a given day to adjust the system. Similarly, on a given day the household may anticipate being unable to irrigate the next morning, and thus be reluctant to skip that day’s evening application despite windy conditions. This would explain *intra*-household variations in the observed weekly irrigation patterns.

Regarding potentially confounding effects, our econometric specification controls for unobserved, invariant household effects, as well as weekly climate conditions. Therefore, the main concern in this respect would be confounding effects that vary both over time and across households. Most notably, one might surmise that whenever a household anticipates a week with high water need, it may switch to a more conservative watering pattern consistent with official regulations to lower the risk of fines. This would confound any causal link between the degree of adherence to the official schedule and water use. This conjecture builds on two underlying assumptions: (i) Households’ weekly irrigation needs change from week to week in a heterogeneous fashion and (ii) households care about enforcement and fines. We argue that neither one is very likely.

To start, the most plausible reason that could drive a sudden need to use more water in a given week for *irrigation* purposes would be an extreme climate event, such as the anticipation of a very hot or dry week. Perhaps some households are more vulnerable to such extreme events than others, given vegetation cover, soil quality, and other landscape-related features. However, as is evident from [Table 2](#) the local climate during our summer research period is uniformly hot and dry. There is not a single day of precipitation, and the daily temperature range is quite narrow. The only variation comes through *daily* and rather random wind patterns, and those cannot be anticipated on a weekly basis. Thus, it is rather unlikely that any given customer experiences pronounced changes in weekly irrigation *demand* over our research period.

In addition, it is equally unlikely that the threat of a penalty would induce customers to switch from a flexible to a compliant weekly pattern, even if such heterogeneous, time-varying changes in water need existed. As stated above, the enforcement of the official watering schedule is very lenient, and fines are nominal. A household receives two warnings for blatant violations before a fine of \$75 is issued. Thus, it is rather unlikely that the threat of low fine, collected with low probability, is sufficient to induce a change in behavior, irrespective of weekly water need.

[Appendix B](#) provides further evidence against this “comply if anticipated use is high” hypothesis. In summary, we feel confident to proceed with our analysis even in absence of an ideal setting with exogenous policy variation for all treatments of interest.

## 4. Descriptive analysis

### 4.1. Classification of weekly irrigation patterns

Establishing a link between consumption and weekly watering patterns requires the identification of outdoor watering events for a given household and day. Specifically, our objective is to sort the daily observations for each household into two categories: (i) days with some outdoor water use and (ii) days with indoor-only water use.

This categorization is challenging since we only observe total daily use rather than usage for different purposes. Ideally, outdoor watering days should be clearly identifiable as pronounced spikes in a customer’s series of observed consumption days. However, the distinction between categories becomes blurred for households with limited need for outdoor watering or high fluctuations in indoor use. We therefore use a series of household-specific *K*-means clustering algorithms ([MacQueen, 1967](#)) to sort daily observations into a low use (“indoor only”) and high use (“indoor plus some outdoor watering”) category. The details of this identification strategy are given in [Appendix B](#).

### 4.2. Descriptive results

Our analysis of OWR design effects requires aggregating the daily sample to a weekly format. [Table 3](#) provides a summary of cell counts and sample percentages for the different week-type categories and watering frequencies. For ease of exposition

**Table 3**  
 Cell counts and percentages by watering frequency and week-type.

Weekly watering days	2008			2010		
	Count	% of sample	% all w/in	Count	% of sample	% all w/in
<i>Schedule-based</i>						
2 <sup>a</sup>	14,497	27.5	42.8	–	–	–
3 <sup>b</sup>	6374	12.1	9.2	12,625	26.0	35.1
4	5595	10.6	16.1	3650	7.5	3.3
>4	6053	11.5	11.6	6001	12.4	15.7
Total	32,519	61.7	25.8	22,276	45.9	24.7
<i>Off-schedule</i>						
0	2924	5.6	0.0	2822	5.8	0.0
1	4198	8.0	1.6	3979	8.2	0.9
2	4795	9.1	5.5	8004	16.5	9.9
3	4257	8.1	7.4	6256	12.9	8.4
4	2610	5.0	6.1	3518	7.2	7.4
>4	1363	2.6	6.5	1718	3.5	2.5
Total	20,147	38.3	4.4	26,297	54.1	6.3
<i>All</i>						
0	2924	5.6	0.0	2822	5.8	0.0
1	4198	8.0	1.6	3979	8.2	0.9
2	19,292	36.6	35.5	8004	16.5	9.9
3	10,631	20.2	9.0	18,881	38.9	28.9
4	8205	15.6	13.2	7168	14.8	5.4
>4	7416	14.1	10.8	7719	15.9	12.9
Total	52,666	100.0	18.5	48,573	100.0	15.8

<sup>a</sup> “Schedule” group for 2008.

<sup>b</sup> “Schedule” group for 2010.

we combine *S* and *SP* weeks into the broader *SB* category, as defined above.<sup>8</sup> The sparsely populated weekly frequencies of five and higher are captured as a single “>4” category. The first half of the table shows results for 2008, while the second provides summaries for 2010. The table has three blocks of rows, corresponding to *SB* weeks, *OS* weeks, and the combined sample. The “percent of sample” column relates row counts to the entire sample size for each year. For example, *SB* weeks with twice watering (i.e. the *S* group by our definition above) comprise 27.5% of the entire 2008 sample. Overall, watering patterns that are perfectly compliant with the official schedule comprise the largest sample share and account for just over a quarter of all sample weeks.

The “percent all within” column reports the percentage share for a given row count that corresponds to households that have *all* their observations in that very category. For example, approximately 42.8% of the observations in the *S* category for 2008 come from households that *always* water twice and on their assigned days. Yet, the majority of customers exhibit seasonal water patterns that include a mix of different week-types and frequencies – only 18.5% of sample weeks in 2008 and 15.5% in 2010 are associated with customers that always water with the same weekly frequency. This is important for our analysis below as it suggests that the observed differences in use and peaks between *SB* and *OS* week-types are *not* driven by unobserved household characteristics.

Table 4 depicts weekly use and peak by frequency and week-type. We stress three key results captured by this table. First, regardless of watering pattern, consumption increases with weekly frequency. This is consistent with prior work showing that capping weekly watering frequency reduces total use. Second, peaks remain relatively stable across frequencies in the two to four applications range. Third – and most importantly – weekly consumption and peaks are substantially higher for weeks that include all assigned days (“schedule-based”) compared to weeks of identical frequency with more flexible watering patterns (“off-schedule”). In 2008, these differences amount to 30–40% for weekly consumption and 50–60% for weekly peak. In 2010 these differentials are slightly attenuated amounting to 25–30% for use and 24–26% for peak.<sup>9</sup>

<sup>8</sup> We stress that our classification into different watering patterns applies to a given *household-week*, not a specific *household* across the entire research period. As discussed in the next section, the majority of households switches frequently between weekly watering patterns. Therefore, there does not exist a clear and systematic classification at the household level that distinguishes along this key dimension of decreasing schedule-adherence. However, we do control for observable and unobservable household characteristics in our econometric specification.

<sup>9</sup> The patterns captured in Tables 3 and 4 are qualitatively similar for the overlap sample. Consumption is approximately 25–35% higher for the *SB* group than the *OS* group at all frequencies. Similarly, *SB* peaks exceed *OS* peaks by 45–55%. Summary statistics for the overlap sample are available from the authors upon request.

**Table 4**  
 Weekly use and peak by watering frequency and week-type.

Weekly watering days	Weekly use (1000 gals.)				Weekly peak (1000 gals.)			
	2008		2010		2008		2010	
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
	<i>Schedule-based</i>				<i>Schedule-based</i>			
2	5.84	(3.67)	-	-	2.34	(1.68)	-	-
3	6.72	(4.56)	5.39	(2.44)	2.30	(1.85)	1.65	(0.83)
4	7.24	(5.04)	5.95	(2.89)	2.19	(1.86)	1.67	(0.96)
>4	9.83	(7.73)	7.32	(4.41)	2.43	(2.26)	1.70	(1.14)
Total	6.99	(5.26)	6.00	(3.26)	2.32	(1.86)	1.66	(0.95)
	<i>Off-schedule</i>				<i>Off-schedule</i>			
0	2.44	(2.20)	2.03	(1.52)	0.55	(0.48)	0.46	(0.34)
1	3.38	(2.61)	2.73	(1.85)	1.30	(1.29)	1.04	(0.94)
2	4.20	(3.20)	3.82	(2.23)	1.46	(1.39)	1.37	(0.98)
3	4.80	(3.61)	4.32	(2.58)	1.42	(1.28)	1.31	(0.95)
4	5.52	(4.64)	4.75	(3.00)	1.47	(1.47)	1.31	(1.04)
>4	6.99	(5.80)	5.65	(4.53)	1.67	(1.63)	1.37	(1.24)
Total	4.26	(3.71)	3.83	(2.71)	1.30	(1.32)	1.20	(0.99)
	<i>All</i>				<i>All</i>			
0	2.44	(2.20)	2.03	(1.52)	0.55	(0.48)	0.46	(0.34)
1	3.38	(2.61)	2.73	(1.85)	1.30	(1.29)	1.04	(0.94)
2	5.43	(3.63)	3.82	(2.23)	2.12	(1.65)	1.37	(0.98)
3	5.95	(4.31)	5.03	(2.54)	1.95	(1.70)	1.53	(0.89)
4	6.69	(4.98)	5.36	(3.01)	1.96	(1.78)	1.49	(1.01)
>4	9.31	(7.50)	6.95	(4.49)	2.29	(2.18)	1.63	(1.17)
Total	5.95	(4.91)	4.82	(3.17)	1.93	(1.75)	1.41	(1.00)

**5. Econometric framework**

To examine if these descriptive results hold up when controlling for climate variations, household characteristics, and unobserved household effects we now turn to our econometric analysis. We assume that over the course of a week a given household makes daily choices on watering occurrence and total use, given watering. From the analyst’s perspective these choices will be observed as joint weekly outcomes on frequency, use, and peak. We thus define such an *observed* weekly irrigation scheme (*IR*) by household *i* in period *p* as a bundle of frequency  $y_{1ip}$  (zero to seven), total use  $y_{2ip}$ , weekly peak  $y_{3ip}$ , and schedule-based pattern (*SB* vs. *OS*), i.e.

$$IR_{ip} = IR(y_{1ip}, y_{2ip}, y_{3ip}, SB_{ip}), \quad i = 1, \dots, N, p = 1, \dots, P \tag{1}$$

where  $SB_{ip}$  is an indicator equal to one if the weekly irrigation pattern corresponds to a schedule-based implementation, and equal to zero for an off-schedule pattern.

Thus, we have three outcomes of interest –  $y_{1ip}$ ,  $y_{2ip}$ , and  $y_{3ip}$ . The first outcome, the number of watering days in a given week, takes the form of an integer that is naturally truncated from above at  $U=7$ . The remaining outcomes, weekly consumption and peak, are continuous with support over  $\mathfrak{R}^+$ . We wish to identify the effect of weekly watering frequency and degree-of-adherence to the OWR on use and peak. If household decisions on use and peak were completely independent from decisions related to weekly frequency, the three outcomes of interest could, in theory, be analyzed via independent estimation. For example, the use and peak equations could be estimated via simple random effects (RE) regression that includes difference-in-difference type interaction terms to capture the incremental effects of weekly frequency, irrigation pattern (*SB* vs. *OS*) and policy change (2008 vs. 2010).

However, if the frequency equation shares common unobservables with either or both of the use or peak equation, such naïve independent analysis would produce misleading results, as the right-hand-side variable “frequency” would introduce endogeneity problems. We find this to indeed be the case in comparative estimation runs.<sup>10</sup> Thus, a plausible econometric model for this application must accommodate the following key features: (i) limitations on the natural range of the dependent variable, (ii) household-specific effects to control for unobserved heterogeneity, and (iii) an ex-ante unrestricted covariance matrix for these unobserved effects, i.e. full correlation of all three equations. To incorporate these modeling challenges in a computationally tractable fashion we deviate from a standard linear regression framework and classical estimation, and turn instead to a hierarchical system approach, estimated via Bayesian tools.

<sup>10</sup> The results for these RE regressions and a discussion thereof are provided in Appendix E.

As point of departure, we combine a truncated Poisson density for the watering frequency equation with two exponential densities for weekly consumption and peak [see e.g. Munkin and Trivedi, 2003].<sup>11</sup> Adding the household effects yields our full specification, which we label the Hierarchical Truncated Poisson–Exponential (HTPE) model. The Hierarchical Truncated Poisson (HTP) component of the HTPE is given as

$$f(y_{1ip} | \lambda_{1ip}, 0 \leq y_{1ip} \leq U) = \frac{\exp(-\lambda_{1ip}) \lambda_{1ip}^{y_{1ip}}}{y_{1ip}! (\sum_{k=0}^U \lambda_{1ip}^k / k!)} \quad \text{with} \quad (2)$$

$$E(y_{1ip}) = \lambda_{1ip} = \exp(\mathbf{x}_{1ip}' \boldsymbol{\beta}_1 + u_{1i})$$

where the log of the untruncated expectation,  $\lambda_{1ip}$ , is a linear function of vector  $\mathbf{x}_{1ip}$  containing household and climate variables, and individual-specific effect  $u_{1i}$ .<sup>12</sup>

The Hierarchical Exponential (HE) part is specified as

$$f(y_{jip} | \lambda_{jip}) = \lambda_{jip} \exp(-\lambda_{jip} y_{jip})$$

$$\lambda_{jip} = \exp(-\mathbf{z}_{jip}' \boldsymbol{\psi}_j - \mathbf{d}_{ip}' \boldsymbol{\delta}_j - u_{ji}) \quad (3)$$

$$E(y_{jip}) = \lambda_{jip}^{-1} = \exp(\mathbf{z}_{jip}' \boldsymbol{\psi}_j + \mathbf{d}_{ip}' \boldsymbol{\delta}_j + u_{ji}), \quad j = 2, 3$$

where the  $\mathbf{z}$ -vectors capture again household and climate information, the random terms are as in (2) and  $E$  denotes the expectation operator. Importantly, vector  $\mathbf{d}_{ip}$  comprises a set of  $U$  indicator variables, one for each possible value of  $y_{1ip}$  that exceeds zero. The element of  $\mathbf{d}_{ip}$  corresponding to the observed value of  $y_{1ip}$  is set to one, all others to zero. More concisely:

$$d_{ip,k} = \begin{cases} 1 & \text{if } y_{1ip} = k, \\ 0 & \text{otherwise} \end{cases} \quad k = 1, \dots, U \quad (4)$$

Thus, we are allowing the intercept of the logged expectation of  $y_{jip}$ ,  $j = 2, 3$ , to shift with the observed number of watering days compared to the implicit baseline of zero outdoor watering. This implies a proportional change of  $\exp(\mathbf{d}_{ip}' \boldsymbol{\delta}_j)$  for the expectation in absolute terms.

The model is completed by stipulating a joint density for the household effect:

$$\mathbf{u}_i = u_{i1} \quad u_{i2} \quad u_{i3} \sim mvn(\mathbf{0}, \mathbf{V}_u) \quad (5)$$

where  $mvn$  denotes the multivariate normal density, and the variance matrix is ex ante unrestricted. As mentioned above, if this matrix contains non-zero covariances, a naïve model ignoring the linkage across the three equations would be plagued by endogeneity bias, since the frequency indicator  $\mathbf{d}_{ip}$  appears on the right hand side of both the use and peak equation.<sup>13</sup>

Letting  $\boldsymbol{\beta}_2 = [\boldsymbol{\psi}_2' \quad \boldsymbol{\delta}_2']'$ ,  $\boldsymbol{\beta}_3 = [\boldsymbol{\psi}_3' \quad \boldsymbol{\delta}_3']'$ ,  $\boldsymbol{\beta} = [\boldsymbol{\beta}_1' \quad \boldsymbol{\beta}_2' \quad \boldsymbol{\beta}_3']'$ , and collecting all outcomes and explanatory data in vector  $\mathbf{y}$  and matrix  $\mathbf{X}$ , respectively, the likelihood function for our model over all individuals  $i = 1, \dots, N$ , unconditional on error terms, takes the following form:

$$p(\mathbf{y} | \boldsymbol{\beta}, \mathbf{V}_u, \mathbf{X}) = \prod_{i=1}^N \int_{\mathbf{u}_i} \left( \prod_{p=1}^P \left( \frac{\lambda_{1ip}^{y_{1ip}}}{y_{1ip}! (\sum_{k=0}^U \lambda_{1ip}^k / k!)} \lambda_{2ip} \lambda_{3ip} \exp(-(\lambda_{2ip} y_{2ip} + \lambda_{3ip} y_{3ip})) \right) \right) f(\mathbf{u}_i | \mathbf{V}_u) d\mathbf{u}_i \quad (6)$$

Given the  $N$  multi-dimensional integrals over  $\mathbf{u}_i$  this model would be challenging to estimate using conventional Maximum Likelihood procedures. We therefore employ a Bayesian estimation framework.

We begin by specifying the prior distribution for the primary model parameters,  $\boldsymbol{\beta}$  and  $\mathbf{V}_u$ . We choose a standard multivariate normal prior for  $\boldsymbol{\beta}$ , and inverse Wishart (IW) priors for  $\mathbf{V}_u$ , i.e.  $\boldsymbol{\beta} \sim mvn(\boldsymbol{\mu}_0, \mathbf{V}_0)$ ,  $\mathbf{V}_u \sim IW(\psi_0, \boldsymbol{\Psi}_0)$ . The IW parameters are the degrees of freedom and scale matrix, respectively. The IW density is parameterized such that  $E(\mathbf{V}_u) = (\psi_0 - k_r - 1)^{-1} \boldsymbol{\Psi}_0$ . We facilitate the implementation of our posterior simulator (Gibbs Sampler) by augmenting the model with draws of the error components  $\{\mathbf{u}_i\}_{i=1}^N$ .<sup>14</sup> The augmented posterior distribution is proportional to the priors times the augmented likelihood, i.e.

$$p(\boldsymbol{\beta}, \mathbf{V}_u, \{\mathbf{u}_i\}_{i=1}^N | \mathbf{y}, \mathbf{X}) \propto p(\boldsymbol{\beta}) \times p(\mathbf{V}_u) \times p(\{\mathbf{u}_i\}_{i=1}^N | \mathbf{V}_u) \times p(\mathbf{y} | \boldsymbol{\beta}, \{\mathbf{u}_i\}_{i=1}^N, \mathbf{X}) \quad (7)$$

<sup>11</sup> The exponential component has similar distributional characteristics as the familiar log-normal regression model, but exhibits more desirable mixing properties in our Bayesian estimation framework.

<sup>12</sup> It should be noted that the restrictive mean–variance equality that is a prominent feature of the standard Poisson density no longer holds under truncation (e.g. Rider, 1953). A second reason for the mean–variance equality to break down is the inclusion of the random household effect. See, for example Hausman et al. (1984).

<sup>13</sup> We also included an observation-specific error in an earlier specification. The parameter estimates generated by that model were virtually identical to those produced by the single-error specification, and both variances and covariances associated with the observational error emerged of negligible magnitude compared to the variance component for the individual-level effect.

<sup>14</sup> The data augmentation step circumvents the need to directly evaluate the integrals in (6). A general discussion of the merits of this technique of data augmentation is given in Tanner and Wong (1987). Applications with data augmentation involving hierarchical count data models include Chib et al. (1998) and Munkin and Trivedi (2003).

**Table 5**  
 Estimation results for frequency equation and error terms.

	Mean	Std.	Prob(>0)
Constant	−4.415	(0.519)	0.000
mintemp	−0.050	(0.050)	0.161
maxtemp	0.151	(0.048)	0.999
avgwind	−0.988	(0.281)	0.000
maxwind	0.407	(0.134)	1.000
gdd	0.022	(0.012)	0.958
Inland	0.087	(0.007)	1.000
lnvalue	0.237	(0.010)	1.000
year2010	4.129	(0.731)	1.000
mintemp × 2010	−0.198	(0.064)	0.001
maxtemp × 2010	−0.395	(0.086)	0.000
avgwind × 2010	0.760	(0.295)	0.997
maxwind × 2010	−0.281	(0.139)	0.019
gdd × 2010	0.061	(0.019)	0.999
Std.'s and corr.'s for $\mathbf{u}_i$			
$\sigma_1$	0.434	0.004	1.000
$\rho_{12}$	0.056	0.014	1.000
$\sigma_2$	0.477	0.005	1.000
$\rho_{13}$	−0.005	0.014	0.364
$\rho_{23}$	0.985	0.001	1.000
$\sigma_3$	0.527	0.005	1.000

Mean = posterior mean; std. = posterior standard deviation; prob(>0) = share of posterior density to the right of zero.

where the last term describes the likelihood function conditioned on all error terms.

The Gibbs Sampler draws consecutively and repeatedly from the conditional posterior distributions  $p(\boldsymbol{\beta}|\{\mathbf{u}_i\}_{i=1}^N, \mathbf{y}, \mathbf{X})$ ,  $p(\mathbf{V}_u|\{\mathbf{u}_i\}_{i=1}^N)$ , and  $p(\{\mathbf{u}_i\}_{i=1}^N|\boldsymbol{\beta}, \mathbf{V}_u, \mathbf{y}, \mathbf{X})$ . Draws of  $\boldsymbol{\beta}$  and  $\{\mathbf{u}_i\}_{i=1}^N$  require Metropolis–Hastings (MH) subroutines in the Gibbs Sampler. Posterior inference is based on the marginals of the joint posterior distribution.<sup>15</sup>

## 6. Estimation results

### 6.1. Posterior results

The regressors in the parameterized expectation of the frequency equation include a combination of home characteristics and climatic variables to control for temperature and wind speed, in addition to an indicator for the 2010 irrigation season and the interaction of this indicator with the various climate variables. The parameterized mean functions for use and peak include additional home characteristics that control for indoor water use and exclude some of the climate variables for identification purpose. These equations also feature indicators for weekly watering frequency, the interaction of these terms with indicators for the 2010 watering season and schedule based weekly watering patterns, and the two-fold interaction of the schedule based and 2010 indicators with both our frequency variables and different wind measures.<sup>16</sup>

We estimate all models using the following vague but proper parameter settings for our priors:  $\boldsymbol{\mu}_0 = \mathbf{0}$ ,  $\mathbf{V}_0 = 100 \times I_k$ ,  $\psi_0 = 5$ , and  $\boldsymbol{\Psi}_0 = I_3$ . We discard the first 20,000 draws generated by the Gibbs Sampler as “burn-ins”, and retain the following 10,000 draws for posterior inference. We assess convergence of the posterior simulator using Geweke’s (1992) convergence diagnostics (CD). These scores clearly indicate convergence for all parameters. To gauge the degree of serial correlation in our Markov chains we also compute autocorrelation coefficients at different lags for all model parameters. These AC values drop below 0.25 by the 10th lag for most parameters, and by the 20th lag for all model elements. This indicates that our posterior simulator has reasonably efficient mixing properties.

The posterior results for the frequency equation are shown in Table 5. The table also captures the results for the elements of the error variance matrix  $\boldsymbol{\Sigma}$ , expressed as standard deviations and correlations. For each parameter we report posterior means, posterior standard deviations, and the probability mass of a given marginal posterior that lies above the zero-threshold. The effects of our various climatic controls are as expected. For example, the frequency of weekly watering events is higher on weeks with higher maximum daily temperatures and lower on weeks with higher average daily wind speeds. Interesting, however, the effect of such controls are attenuated for the 2010 season. Taken jointly, our data thus suggest that climate conditions have a more pronounced effect on the variability of watering frequency when the official OWR ceiling is lower.

Turning to the elements of  $\boldsymbol{\Sigma}$  in the lower half of Table 5, we note that with exception of  $\rho_{13}$  all terms are estimated with high precision (i.e. exhibit low posterior standard deviation relative to the mean). The standard deviations (labeled  $\sigma_j, j = 1,$

<sup>15</sup> The detailed steps of the posterior simulator and the Matlab code to implement this model are available from the authors upon request.

<sup>16</sup> Details on household and climate regressors are provided in Appendix D.

**Table 6**

Estimation results for use and peak equations.

	Weekly use			Weekly peak		
	Mean	Std.	Prob(>0)	Mean	Std.	Prob(>0)
Constant	−10.766	(0.773)	0.000	−12.706	(0.766)	0.000
freq1	0.392	(0.025)	1.000	0.883	(0.026)	1.000
freq2	0.584	(0.025)	1.000	0.980	(0.026)	1.000
freq3	0.720	(0.026)	1.000	0.989	(0.027)	1.000
freq4	0.821	(0.029)	1.000	0.992	(0.031)	1.000
freq567	0.967	(0.036)	1.000	1.048	(0.036)	1.000
SB × freq2	0.208	(0.066)	1.000	0.379	(0.068)	1.000
SB × freq3	0.197	(0.066)	0.999	0.334	(0.068)	1.000
SB × freq4	0.179	(0.068)	0.995	0.307	(0.071)	1.000
SB × freq567	0.200	(0.071)	0.999	0.233	(0.072)	0.999
year2010	0.185	(0.740)	0.593	−0.178	(0.730)	0.403
freq1 × 2010	−0.010	(0.036)	0.393	−0.009	(0.036)	0.385
freq2 × 2010	0.034	(0.035)	0.837	0.073	(0.035)	0.978
freq3 × 2010	0.045	(0.036)	0.895	0.071	(0.036)	0.977
freq4 × 2010	0.053	(0.041)	0.901	0.092	(0.041)	0.990
freq567 × 2010	0.038	(0.049)	0.786	0.064	(0.048)	0.909
SB × freq3 × 2010	−0.052	(0.144)	0.361	−0.257	(0.147)	0.039
SB × freq4 × 2010	−0.049	(0.146)	0.357	−0.244	(0.150)	0.049
SB × freq567 × 2010	−0.041	(0.147)	0.395	−0.200	(0.151)	0.088

Results for household and climate variables are omitted for brevity, but are given in [Appendix D](#). Mean = posterior mean; Std. = posterior standard deviation; Prob(>0) = share of posterior density to the right of zero.

... 3) are of non-negligible magnitude, which confirms the presence of unobserved household effects in all three equations. Household unobservables are highly correlated for equations two and three, and we find a mild, positive correlation between the frequency and the use equations.<sup>17</sup>

Posterior results for the weekly use and peak equations are summarized in [Table 6](#). Regarding weekly use, the table captures three main results. First, consumption increases clearly with weekly frequency. Furthermore, this result remains essentially unchanged in 2010. Second, weeks associated with schedule-based (SB) watering exhibit increased use compared to the implicit off-schedule (OS) baseline at any frequency. These rigidity penalties amount to 20–23%, and are highest for weeks that follow the official schedule exactly.<sup>18</sup> Third, controlling for frequency and watering pattern, the residual policy effect is of negligible magnitude.

The results for weekly peak are given in the last three columns of the table. In contrast to use, peaks do not change much over frequency in either year. However, as for use, peaks are substantially larger for SB-type weeks compared to OS-type patterns in 2008, and this difference is greater at lower frequency levels. This gap diminishes in 2010, as peaks for SB-type implementations decrease by 18–23% compared to the 2008 season, and peaks for OS-types increase slightly (by 6–9%). The reduction in the “rigidity penalty” for peaks in 2010 compared to 2008 likely reflects the additional flexibility afforded to compliant customers by the revised OWRs. Schedule-adherent households now have more options to reduce daily watering on windy days and are less likely to face the dilemma of incurring wind losses or violating official rules by making up for a skipped application on non-assigned days.

However, we also acknowledge that to some extent this reduction in rigidity gap, especially via increased peaks for OS-types, might be an artifact of our classification scheme: Some 2010 customers may have been sluggish to adjust to the new schedule. As a result, the “rigid” weeks produced by these residents, classified as SB in 2008, are counted as OS-types in 2010.<sup>19</sup> As such, our estimates can be interpreted an upper bound on the effect of the policy change on the rigidity penalty for peak use.

The remaining findings for the peak model mirror those from the weekly use equation: namely, there are no noteworthy residual policy effects. Overall, we conclude that the results produced by our complete econometric specification support the descriptive findings from the preceding section.

<sup>17</sup> As illustrated in the [Appendix E](#), this linkage via unobservables between equations one and two is sufficient to produce inconsistent parameter estimates for both use and peak models if the system is estimated via independent random effects regressions.

<sup>18</sup> We use the conversion formula of  $\exp(\beta) - 1$  suggested by [Halvorsen and Palmquist \(1980\)](#) to interpret marginal effects associated with binary variables, given the log-normal form of the parameterized mean function.

<sup>19</sup> Recall that every SB designated week must include outdoor use on all assigned days. Hence, any 2008 schedule-adherent household who fails to adjust to the new OWRs by watering on the third allowable day and switching to the new assigned week-days during 2010 would produce OS-type weeks for that year – even if there was no change in the actual watering pattern relative to the 2008 season.

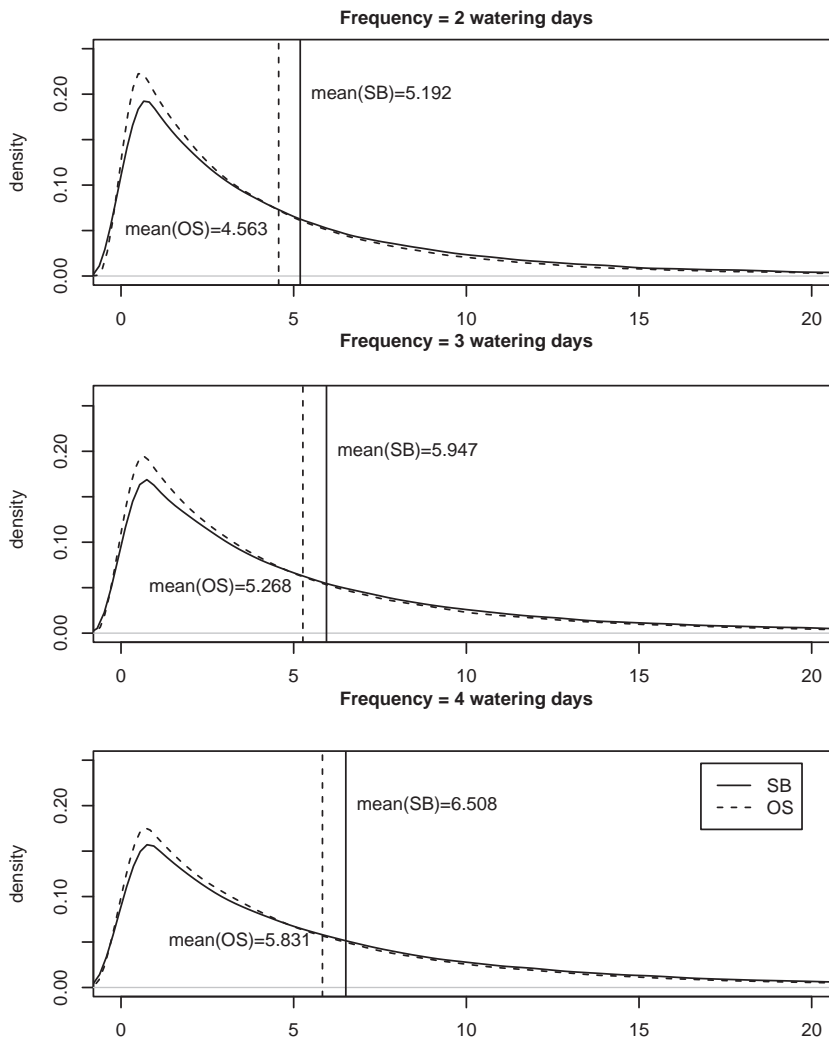


Fig. 1. Predictive distributions of weekly use for a typical household (1000 gallons).

6.2. Predictive analysis

For a more direct comparison of weekly consumption and peak across weeks with different watering patterns we generate posterior predictive densities (PPDs) for each irrigation type (SB vs. OS). Formally, these PPDs are given as

$$p(y_j | \mathbf{x}_{tf}) = \int_{\boldsymbol{\theta}} \left( \int_{u_{ij}} ((y_j | \mathbf{x}_{tf}, \boldsymbol{\beta}, u_{ij}) f(u_{ij} | \mathbf{V}_u)) du_{ij} \right) p(\boldsymbol{\theta} | \mathbf{y}, \mathbf{X}) d\boldsymbol{\theta}, \quad j = 2, 3, \tag{8}$$

where  $\mathbf{x}_{tf}$  denotes a specific combination of watering pattern  $t \in \{SB, OS\}$  and frequency  $f \in \{2, 3, 4\}$ , and vector  $\boldsymbol{\theta}$  comprises the entire set of model parameters. In practice, we simulate these PPDs by (i) drawing 10 random coefficients from  $f(u_{ij} | \mathbf{V}_u)$ , (ii) computing  $\lambda_{ij}$  for each  $u_{ij}$  as given in (2), and (iii) drawing  $y_j$  from the exponential density with expectation  $\lambda_{ij}$ . We repeat steps (ii) and (iii) for all 10 draws of  $u_{ij}$ , and steps (i) through (iv) for all 10,000 draws of  $\boldsymbol{\theta}$  from the original Gibbs Sampler.

Except for the combination  $t=SB, f=2$ , which is only meaningful for 2008, we derive separate PPDs for  $y_j | \mathbf{x}_{tf}$  for 2008 and 2010 by setting the 2010 indicator and interaction terms accordingly in the covariate matrix for the use and peak equations. We combine these year-specific PPDs for final analysis as there is discernible difference in watering behavior across these years once we control for climatic and household specific variables. The latter are set to their grand sample means for this predictive analysis.

The resulting PPDs are depicted in Fig. 1 for use and Fig. 2 for peak. Each subplot shows PPDs for SB and OS types for a given frequency. Posterior predictive expectations are superimposed as vertical lines and labeled with their respective numerical value (in 1000 gallons). As is evident from Fig. 1, the SB pattern produces higher expected use than the OS pattern

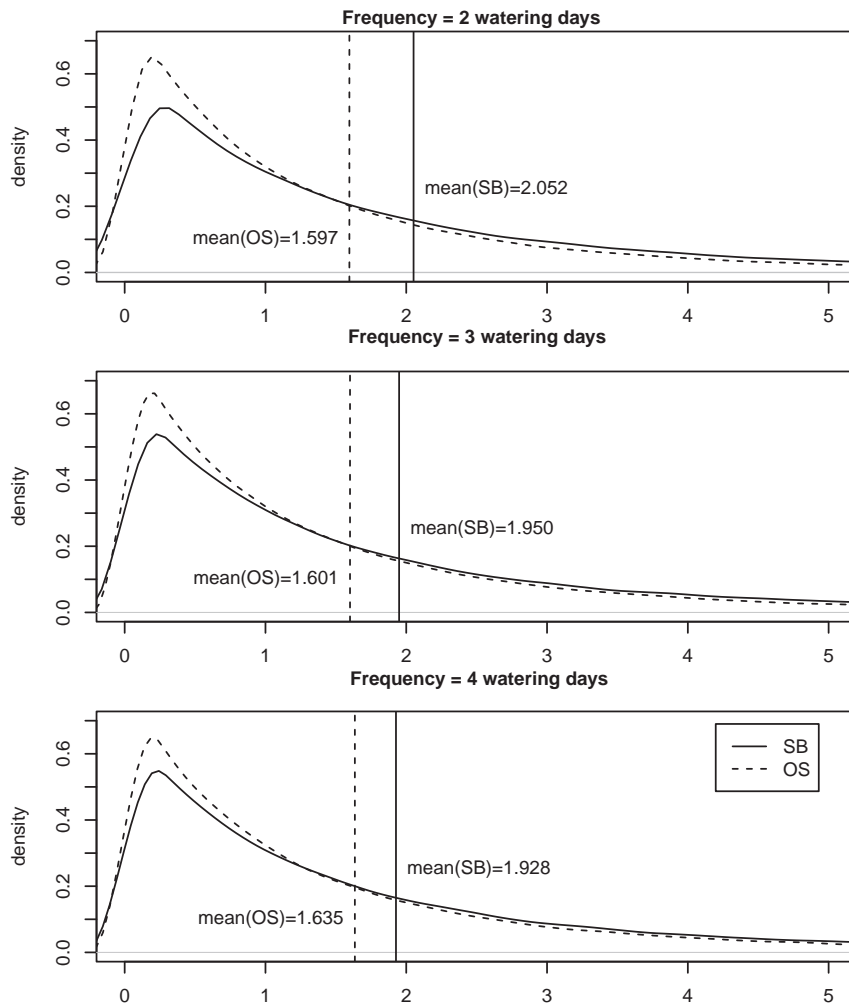


Fig. 2. Predictive distributions of weekly peak for a typical household (1000 gallons).

at all frequencies, with a slightly decreasing relative gap from 14% at  $f=2$ –12% at  $f=4$ . As shown in Fig. 2 these differences in posterior predictive expectation are even more pronounced for peak. At two watering days, the SB pattern generates a peak that is approximately 28% higher than the OS peak. At three watering days, this difference reduces to 22%, and at a frequency of four it amounts to close to 18%. Overall, these predictive results support our descriptive and analytical findings – a watering pattern that closely follows the officially assigned days produces noticeably higher weekly consumption and substantially higher peaks than a more flexible distribution of the same number of watering days across a given week.

## 7. The wind effect

As mentioned at the onset, we believe that the assignment of household-weeks into different watering patterns is largely driven by exogenous shocks in the form of high wind events. Specifically, some customers switch to more flexible irrigation patterns to avoid wind-induced water losses. Conversely, households that follow the assigned schedule are more likely to water under adverse natural conditions such as high wind events. This increases both use and peak, as it takes more water per week and per daily application to provide adequate irrigation for a given landscape.

To explore this conjecture in greater detail, we compute the percentage of watering days that fall on either a windy or very windy day.<sup>20</sup> The results are captured in Table 7. In 2008 the average watering day had a 51% chance of occurring on a windy day and an 18% chance of coinciding with a very windy day. Importantly, these percentages are higher for the SB group compared to the OS segment at essentially all frequencies. In 2008, this difference is especially pronounced for the

<sup>20</sup> “Windy days” are those with a maximum sustained wind speed that exceeds the sample mean (16.51 knots). “Very windy” days are defined as those with a maximum sustained wind speed at the 75th percentile (19 knots) or higher.

**Table 7**  
 Wind events by watering frequency and week type.

Weekly watering days	2008		2010		All	
	% windy	% very windy	%windy	% very windy	%windy	% very windy
<i>Schedule-based</i>						
2	57.02	21.40	–	–	57.02	21.40
3	52.32	19.50	48.82	18.09	50.00	18.57
4	52.21	19.37	48.58	17.66	50.78	18.69
>4	46.75	15.29	47.09	17.34	46.92	16.32
Total	51.71	18.58	48.08	17.72	50.06	18.19
<i>Off-schedule</i>						
2	50.68	19.08	47.73	18.38	48.83	18.65
3	48.65	16.60	46.94	17.67	47.63	17.24
4	49.51	17.18	46.99	17.25	48.07	17.22
>4	47.40	15.14	46.58	16.42	46.94	15.85
Total	49.14	17.09	47.11	17.57	47.94	17.37
<i>All</i>						
2	55.44	20.82	47.73	18.38	53.18	20.11
3	50.85	18.34	48.20	17.95	49.15	18.09
4	51.35	18.67	47.80	17.46	49.70	18.11
>4	46.86	15.27	46.99	17.16	46.93	16.23
Total	51.00	18.17	47.70	17.66	49.35	17.91

**Table 8**  
 Random effects probit estimation of daily watering decision (translated into marginal effects).

2008	2010			2010	2010		
	Coeff.	s.e.	z		Coeff.	s.e.	z
<i>Weekly frequ. = 2 (n = 135,044)</i>							
Windy	0.074	0.004	17.870				
Windy × SB	0.049	0.004	12.070				
Avg. temp.	0.011	0.000	25.190				
<i>Weekly frequ. = 3 (n = 74,417)</i>							
Windy	0.033	0.005	6.290	Windy	0.003	0.004	0.670
Windy × SB	0.053	0.005	9.900	Windy × SB	0.013	0.004	3.030
Avg. temp.	0.005	0.001	8.380	avg. temp.	0.001	0.000	2.730
<i>Weekly frequ. = 4 (n = 57,435)</i>							
Windy	0.055	0.006	8.510	Windy	0.000	0.006	0.070
Windy × SB	0.053	0.006	8.430	Windy × SB	0.016	0.006	2.470
Avg. temp.	0.009	0.001	12.310	avg. temp.	0.001	0.000	1.450

S category – the share of windy days exceeds the corresponding value for OS/twice a week by over 6%. In general, SB type weeks were 3–6% more likely to occur on a windy day and 2–3% more likely to fall on a very windy day than OS type weeks of comparable frequency. In 2010, which had slightly fewer windy days overall compared to 2008, the difference in the relative frequency of wind events across week-types reduces to 1–2% for windy days and falls below the 1% mark for very windy days. However, as for 2008, the S category experiences the highest risk of wind exposure.

To provide more rigorous support for this “wind hypothesis” we estimate a Probit models of daily watering decision on average daily temperature (F), an indicator for “windy day” (with max. sustained speed exceeding the sample mean of 16 knots), an interaction term for “windy” and “SB”, and a random household effect. We estimate separate models for the two sample years, and weekly frequencies of 2, 3, and 4 watering days.

The results are captured in Table 8. For ease of interpretation, the estimated coefficients are presented as marginal effects, conditional on a random effect of zero. As can be seen from the table, in 2008 the probability of a observed watering day to coincide with above-average wind conditions is approximately 5% higher for an “SB” type HW compared to an “OS” type. This difference shrinks to 1–3% in 2010, but is still significant. Thus, the Probit estimates pair up well with our descriptive insights in supporting the conjecture that wind events may well be the main driver of the observed variability in weekly watering patterns, and associated differences in use and peaks across irrigation types.<sup>21</sup>

<sup>21</sup> Irrigation losses due to wind can easily amount to 40–50% in arid climates, even under moderate wind speeds of 10 mph (8–9 knots) or less (Bauder, 2000; Duble, 2013). Naturally, these losses are further exacerbated if even the water that hits the ground completely misses its target, which is a common occurrence for the relatively small yards in our research area.

## 8. Conclusion

This study is the first to examine how the *design* of outdoor watering restrictions impacts residential water use at the household level. Using a unique, customer specific data set of daily consumption over multiple irrigation seasons that include an inter-season policy change, we arrive at several important and novel findings. Most centrally, both the cap on weekly frequency *and* the address-based assignment of specific watering days matter for conservation outcomes. While the former is confirmed to be necessary for curbing consumption, the latter undermines conservation goals.

We find that higher frequencies unambiguously translate into higher weekly use. However, we uncover an unintended consequence of OWRs with days-of-week assignments: weekly use and peak are higher the more closely a given household follows the assigned schedule. These “rigidity penalties” are substantial and amount to approximately 20–25% of weekly consumption and 30–40% of weekly peaks.

The policy change from two to three assigned days per week produced two main effects. First, it induced the intended switch in watering patterns for a considerable segment of customer-weeks. Second, we observe a pronounced reduction in peaks at the system-wide level – an effect driven predominantly by lower peaks for schedule-based weeks. In contrast, overall weekly use changes little in reaction to the new policy.

For policy-makers, our results suggest that adjusting existing OWRs to allow for flexible watering patterns could produce substantial water savings at relatively low implementation costs. Moreover, as inefficiency penalties are highest at low frequencies, our findings also cast doubt on the effectiveness of policies that reduce the number of assigned days under progressively severe drought conditions. In such situations, a frequency reduction combined with a “free-to-choose” policy is likely to promote greater conservation. Naturally, violations of allowed weekly frequencies would be more difficult to detect under such a policy, since permissible applications would no longer be pegged to a given day-of-week for a given address. However, the fact that many current customers adhere – at least loosely – to the official regulations despite weak enforcement by the utility suggests that social norms and “neighborly supervision” may be stronger drivers of compliance than officially posted fines. These norms would still be in force under more flexible policies, as nearby neighbors can easily keep track of other households’ weekly watering frequency.

Our analysis extends prior work exploring the unintended consequences of nested policies, and those that introduce heterogeneous standards across firms and/or regions. Whereas the extant literature focuses on leakages generated by the spatial reallocation of effort, our paper highlights another channel through which leakages may arise – by hampering the temporal reallocation of effort. In our setting, adherence to the official watering schedule requires households to ignore time-varying weather patterns that reduce the efficacy of outdoor watering.

It is easy to envision other domains where similar patterns could arise. For example, many utilities have explored time-of-day pricing as a means to manage residential energy consumption and associated greenhouse gas emissions. To the extent that such pricing schemes cause a shift in demand from peak to non-peak hours, the overall impact on carbon could fall short of expectations as the marginal fuel source during peak hours is often less carbon intensive than base load generators (the marginal fuel source during non-peak periods). The identification of such temporal leakages and the design of policies that are robust to such unintended consequences should provide ample opportunities for future research.

## Appendix A. Outdoor watering restrictions in the United States

See [Table A.9](#).

## Appendix B. Evidence against confounding effects

If there were any other time-varying factors that drive water need in a heterogeneous fashion we should see pronounced variation over time in the fraction of different watering types. [Table B.10](#) shows, for each week of our research period, the number of households included in the sample, and the percentage of watering types. The last two columns of the table capture the two types we use in our empirical model, *SB* and *OS*. For additional insight, we also show the percentage, of the total sample, of perfectly compliant types, or *S* types (which are nested within *SB*). We further split these *S* types into the percentage of household-weeks (HWs) that come from households that *always* follow the schedule (labeled as “always” in the table), and the remaining share of HWs contributed by “occasional” perfect compliers (labeled as “occ”) in the table.

As can be seen from the table, there are no pronounced shifts in the proportion of type assignments over time. This puts in question the proposition that a substantial share of *OS* types become *SB* types due to a systematic weekly shock that affects water need. [Table 2](#) in the main text and [Table B.10](#) combined also show that the hottest weeks in 2008 (week 3) and 2010 (week 4) do *not* produce the highest proportion of *S* or *SB* types in the overall watering pattern.

It is also obvious from [Table B.10](#) that perfectly compliant HWs, or *S* types constitute the minority of *SB* types in any given week. Most HWs that are *SB* have a watering pattern that adds one or more days to the official schedule. In other words, they are already cheating to some extent. Throughout our analysis we compare *SB* types and *OS* types *conditional on the same weekly frequency*. This means that an *OS* type cheats just slightly more than an *SB* type of the same frequency. Therefore, the probability of detection and fines should not be all that different between the two types.

Furthermore, if the “behave to avoid fines when water needs are high” conjecture were to hold, we would expect to see higher use for *S* types compared to one-off *SB* types. For example, in 2008, an *S* type would water exactly twice. We can then

**Table A.9**  
 Examples of cities with outdoor watering restrictions (as of June 1, 2010).

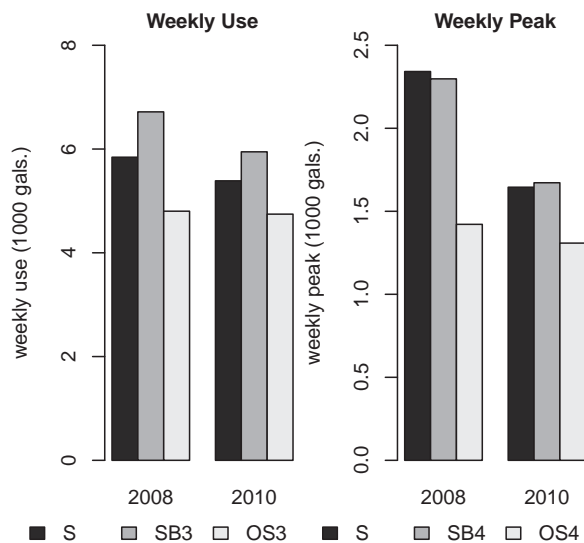
City	Population (1000s)	Utility	Restriction period	Time-of-day restrictions	Days per week restrictions for sprinklers	Assigned watering days for sprinklers	Other restrictions	Special rules for manual watering
<b>CALIFORNIA</b>								
Los Angeles	4095	L.A. Dept. of Water and Power	Ongoing, since June 2009, year-round	No watering 9am–4pm	2 days/week	Mo, Thu only, all addresses	15 min. max. runtime per cycle	None
San Diego	1376	The City of San Diego	Ongoing since June 1, 2009, restrictions change across seasons	No watering 10am–6pm	3 days/week	Assigned by address	10 min. max. run-time per cycle	No restrictions on run-time
Fresno	505	City of Fresno	Ongoing, restrictions change across seasons	No watering 6am–7pm	3 days/week	Assigned by address	Restrictions on landscaping (no bluegrass)	None
Long Beach	495	Long Beach Water	Ongoing	No watering 9am–4pm	3 days/week	Mo, Thu, Sat only, all addresses	10 min. max. run-time per cycle	None
<b>NEVADA</b>								
Las Vegas	478	Las Vegas Valley Water District	Ongoing, since 2002, restrictions change across seasons	No watering 11am–7pm (summer only)	3 days/week (spring, fall only)	Assigned by address	None	Allowed any time, any day
Reno/Sparks	419	Truckee Meadows Water Authority	Ongoing, since 1996, summer only	No watering noon to 6pm	3 days/week <sup>a</sup>	Assigned by address	None	Allowed any time, any day
<b>COLORADO</b>								
Denver	555	Denver Water	May 1–Oct. 1	No watering 10am–6pm	None	N/A	No watering during strong winds or rain; limitations on run-time per cycle	None
<b>TEXAS</b>								
Dallas	1189	Dallas Water Utilities	April 1–Oct. 31	No watering 10am–6pm	None	N/A	No watering during rain	Allowed any time, any day
San Antonio	1145	San Antonio Water System	Year-round (severity of restrictions based on aquifer level)	No watering 10am–8pm	1 day/week (“Stages 1, 2”)	Assigned by address	None	Allowed any time, any day
Austin	657	Austin Water	Ongoing, since Nov.21, 2009	No watering 10am–7pm	2 days/week	Assigned by address	None	Allowed any time, any day
<b>GEORGIA</b>								
Entire State placed under non-drought schedule as of June 1, 2010	9829	Environmental Protection Division	Ongoing, since June 1, 2010 (restrictions become more severe during declared drought)	None	3 days/week	Assigned by address	None	None
<b>FLORIDA</b>								
Jacksonville	835	St. John’s River Water Management District	Ongoing, restrictions change across seasons	No watering 10am–4pm	2 days/week (summer schedule)	Assigned by address	60 min. max. run-time per cycle	None
Miami	391	Miami-Dade Water and Sewer Department	Ongoing, year-round	No watering 10am–4pm	2 days/week (summer schedule)	Assigned by address	None	Allowed daily for 10 min.
Tampa	331	City of Tampa Water Department	Ongoing, year-round	No watering 10am–6pm	1 day/week	Assigned by address	Only one cycle allowed per day	Same as sprinkler rules for lawns, else unrestricted

<sup>a</sup> 2 days 1996–2009, 3 days as of 2010.

**Table B.10**  
 Percentages of watering types over time.

Week	Sample	S			SB	OS
		Always	occ.	Total		
<i>2008</i>						
1	8468	12%	15%	28%	60%	40%
2	8270	13%	16%	29%	61%	39%
3	8572	12%	16%	28%	64%	36%
4	2488	9%	15%	24%	58%	42%
5	3163	9%	15%	25%	60%	40%
6	5825	10%	16%	26%	59%	41%
7	7774	12%	17%	29%	62%	38%
8	7235	12%	14%	26%	66%	34%
9	871	14%	16%	30%	63%	37%
<i>2010</i>						
1	5765	9%	14%	24%	38%	62%
2	7338	9%	15%	24%	43%	57%
3	1853	9%	15%	24%	47%	53%
4	7317	9%	17%	26%	48%	52%
5	7420	9%	18%	27%	48%	52%
6	6074	9%	19%	28%	50%	50%
7	5512	9%	18%	27%	44%	56%
8	7294	9%	18%	27%	47%	53%

SB = schedule-based (all assigned days are used); OS = off-schedule (not all assigned days are used); S = schedule-exact, perfect compliance; S/always = from households that always show perfect compliance; S/occ. = from households that occasionally show perfect compliance.



**Fig. 3.** Weekly use and peak for S and “one-off” types.

compare the resulting weekly use to that of an SB – 3 type that uses one additional day. In the same vein, we can compare an S type for 2010 (3 allowable watering days) to an SB – 4 type. In both cases we would expect use to increase under the S regime under the conjecture.

However, as is evident from Fig. 3, the one-off SB types use *more* water than perfect compliers and have comparable peaks to S types in both years. This picture is more consistent with the notion that when a households needs more water, it simply adds an additional day. This directly contradicts the “revert to S when need is high” hypothesis.

**Appendix C. Identification of outdoor watering days**

Our identification of outdoor watering days thus proceeds in the following steps:

1. We start with a simple K-means clustering algorithm (MacQueen, 1967) at the household level to classify each day as a “high use” or “low use” occurrence. Our objective is to confidently interpret high use days as days with outdoor irrigation, and low-use days as days with strictly non-irrigation consumption. We use six different clustering algorithms. The first

three are based on actual daily use, the second set of three on logged use.<sup>22</sup> Within each set, the first algorithm uses the Euclidean distance between observation points and the current pair of cluster centroids as a sorting criterion, the second uses Euclidean distance squared, and the third absolute distance (Vinod, 1969; Massart et al., 1983). In each case we use the mean consumption on assigned and unassigned days, respectively, as starting values for the cluster centroids.

We find that within each triplet all three algorithms agree on sorting for every single observation in both the 2008 and 2010 data sets. This indicates robustness to the choice of similarity measure, which is reassuring. As expected, the versions based on logged use, which are less sensitive to outliers and thus lower the threshold for observations to fall into the higher category, identify about 10–15% more observations as watering days than the versions based on actual use in gallons in each data set.

However, *all six versions* are in complete agreement for all daily observations associated with 1644 (18.8%) of households in 2008, and 890 households (11.7%) in 2010. These are likely customers that exclusively water via automated sprinkler systems, producing very pronounced differences in usage between irrigation and non-irrigation days. Within these subgroups, the sorting into watering and non-watering days perfectly aligns with *assigned* watering days for 604 (6.9%) of customers in 2008, and 422 (5.5%) of customers in 2010. For these households we can be especially confident that the observations flagged as non-watering days truly and exclusively capture indoor, or non-irrigation, use. In the following, we label these households as “Full Agreement, Full Compliance” (FAFC) cases.

An inspection of sample statistics on basic building and lot characteristics assures us that these FAFC cases are not systematically different in measurable ways from the remainder of the data set.<sup>23</sup> Thus, we deem them suitable as a representative sub-sample that provides reliable and important information on non-irrigation use.

2. Our next goal is to utilize information on winter use and the fact that the Reno/Sparks climate precludes any water use for outdoor irrigation during the cold season to validate the cluster analysis results. Specifically, using available data on monthly consumption during the January–March period preceding our summer data collections, we compute *average daily winter use* and the ratio of daily summer use to average daily winter use for each household in both data sets. Focusing again on the FAFC observations, we then inspect the sample distribution of this ratio for unassigned days. For 2008, the mean and standard deviation for this ratio amount to 2.3 and 2.4, respectively. For 2010, the mean equals 1.85, and the standard deviation is 1.7. According to TMWA, indoor use is higher in summer for the typical household due to factors such as a larger average daily household size as school and college-age children spend more time at home, a higher level of outdoor and athletic activities, increasing water use for drinking, cleaning, laundry, and showers, increased use for the watering of indoor plants, and water use for cooling units. The lower average for 2007 is likely due to the slightly cooler summer that year, as described in the main text.
3. We interpret the above results as indicative of the typical household in the Reno/Sparks area consuming approximately twice as much water per day for non-irrigation purposes in summer than in winter. Based on the standard deviations for the FAFC segment given above, we would further expect daily non-irrigation use for *any household* not to exceed a ratio to winter use in excess of  $3 \times 2.4 = 7.2$  in 2008 and of  $3 \times 1.7 = 5.1$  in 2010.
4. For our final classification step we generally adopt the cluster analysis results based on absolute use, but we recode all observations flagged as “non-watering” days that exceed the three-standard deviation thresholds given above as “watering days”. This results in 19,479 changes (8.2% of observations originally flagged as non-watering) for the 2008 data, and 17,818 changes (8.6% of observations originally flagged as non-watering) for the 2010 set. These recoded observations are likely associated with households that employ some *daily* baseline watering system, as mentioned above. Due to the latency of the baseline irrigation the cluster analysis fails to identify these non-sprinkler days as irrigation days. Adding information on winter use to our analysis allows us to correct this shortcoming.

#### Appendix D. Details on econometric specification and results

The household and climate regressors in the frequency equation are: log of lot size in square feet (“Inland”), log of tax-assessed land value (“Invalue”), the weekly average of, respectively, daily minimum and maximum temperature (“mintemp”, “maxtemp”), the weekly average of daily average wind in knots (“avgwind”), the weekly average of maximum daily sustained wind (“maxwind”), and total weekly growing degree days (“gdd”). For a given calendar day, the latter is computed as (maximum daily temperature + minimum daily temperature)/2 – 50. All climate indicators are measured in units of 10 for a more balanced scaling of the regressor matrix.

Equations two (weekly use) and three (weekly peak) include the additional home features log of square footage (“lnsf”), number of bedrooms, number of water fixtures, and age plus age squared. The dropped climate variables (for identification purpose) are “mintemp”, “maxtemp”, and “gdd”.

The full results for equations two and three are given in Table D.11.

<sup>22</sup> We add an increment of one gallon to each zero-usage observation before taking logs

<sup>23</sup> These comparison tables are available from the authors upon request

**Table D.11**  
 Estimation results for use and peak equations, Bayesian model.

	weekly use			weekly peak		
	Mean	Std.	Prob(>0)	Mean	Std.	Prob(>0)
Constant	-10.766	(0.773)	0.000	-12.706	(0.766)	0.000
freq1	0.392	(0.025)	1.000	0.883	(0.026)	1.000
freq2	0.584	(0.025)	1.000	0.980	(0.026)	1.000
freq3	0.720	(0.026)	1.000	0.989	(0.027)	1.000
freq4	0.821	(0.029)	1.000	0.992	(0.031)	1.000
freq567	0.967	(0.036)	1.000	1.048	(0.036)	1.000
SB × freq2	0.208	(0.066)	1.000	0.379	(0.068)	1.000
SB × freq3	0.197	(0.066)	0.999	0.334	(0.068)	1.000
SB × freq4	0.179	(0.068)	0.995	0.307	(0.071)	1.000
SB × freq567	0.200	(0.071)	0.999	0.233	(0.072)	0.999
Inland	0.389	(0.010)	1.000	0.439	(0.011)	1.000
lnsf	0.170	(0.033)	1.000	0.154	(0.036)	1.000
lnvalue	0.294	(0.028)	1.000	0.344	(0.030)	1.000
fixtures	-0.002	(0.003)	0.324	-0.005	(0.004)	0.079
bedrooms	0.042	(0.009)	1.000	0.032	(0.009)	1.000
age	0.218	(0.011)	1.000	0.280	(0.012)	1.000
age2	-0.020	(0.001)	0.000	-0.025	(0.002)	0.000
avgttemp	0.051	(0.081)	0.735	-0.007	(0.079)	0.470
avgwind	-0.070	(0.453)	0.442	-0.064	(0.462)	0.453
maxwind	0.050	(0.184)	0.615	0.008	(0.188)	0.506
avgwind × SB	-0.222	(0.563)	0.349	0.002	(0.575)	0.500
maxwind × SB	0.032	(0.199)	0.567	-0.058	(0.204)	0.386
year2010	0.185	(0.740)	0.593	-0.178	(0.730)	0.403
freq1 × 2010	-0.010	(0.036)	0.393	-0.009	(0.036)	0.385
freq2 × 2010	0.034	(0.035)	0.837	0.073	(0.035)	0.978
freq3 × 2010	0.045	(0.036)	0.895	0.071	(0.036)	0.977
freq4 × 2010	0.053	(0.041)	0.901	0.092	(0.041)	0.990
freq567 × 2010	0.038	(0.049)	0.786	0.064	(0.048)	0.909
SB × freq3 × 2010	-0.052	(0.144)	0.361	-0.257	(0.147)	0.039
SB × freq4 × 2010	-0.049	(0.146)	0.357	-0.244	(0.150)	0.049
SB × freq567 × 2010	-0.041	(0.147)	0.395	-0.200	(0.151)	0.088
avgttemp × 2010	-0.025	(0.082)	0.391	0.016	(0.080)	0.583
avgwind × 2010	0.333	(0.486)	0.76	0.515	(0.500)	0.848
maxwind × 2010	-0.109	(0.187)	0.258	-0.143	(0.192)	0.240
avgwind × SB × 2010	-0.020	(0.063)	0.372	-0.033	(0.065)	0.304
maxwind × SB × 2010	0.010	(0.021)	0.688	0.021	(0.021)	0.837

mean = posterior mean; std. = posterior standard deviation; prob(>0) = share of posterior density to the right of zero.

**Appendix E. Independent random effects regressions**

If the random household effects were not correlated across the three equations, the parameters in the use and peak models could in theory be consistently estimated via simple, independent random effects regressions. For the coefficients in the mean function consistency in such a naïve independent framework would hold even if equations two and three were correlated, as long as their respective correlations with equation one is truly zero. This is because the dependent variable of equation one, weekly watering frequency, enters the other two equations on the right hand side (in form of binary indicators), and would thus cause endogeneity problems if there existed a link between equation one and the other two models via the unobservable household effects.

From Table 5 in the main text we see that  $\rho_{13}$  is negligible with large posterior uncertainty, but  $\rho_{12}$ , while small, is positive and estimated with relatively high precision. To examine to what extent ignoring this correlation would affect parameter estimates, we run two independent random effects (RE) regressions for weekly use and peak with the exact same regressors as in our Bayesian Hierarchical Exponential (HE) models. The dependent variables are in log-form.

If endogeneity is not an issue, the two frameworks, Bayesian HE, and classical RE, should produce asymptotically identical results for the following reasons: (i) both are based on the same log-linear parameterized mean function, which assures the same interpretation for marginal effects, (ii) the normal density, which forms the basis for the RE regressions, and the exponential density which underlies the HE model, are both in the family of linear exponential distributions. Therefore, a mis-specification of the (combined) variance of error terms in the likelihood function should not affect consistency of coefficient estimates in the parameterized mean function [see e.g. Cameron and Trivedi, 2005, ch. 5], and (iii) while the RE regression has an additional normally distributed idiosyncratic error, both preliminary runs of an expanded Bayesian model and the RE results indicate that the variance of that error term is small compared to the variance of the household effect.<sup>24</sup> Finally, with over 100,000 observations, we would expect good asymptotic properties from both frameworks.

<sup>24</sup> The RE output indicates that 82–86% of total error variability is assigned to the household effect.

**Table E.12**

Estimation results for the independent RE regressions.

	Weekly use Mean	Std.	Weekly peak Mean	Std.
Constant	-8.039	(0.255)***	-10.186	(0.301)***
freq1	0.457	(0.006)***	0.870	(0.008)***
freq2	0.669	(0.006)***	0.980	(0.008)***
freq3	0.818	(0.007)***	1.026	(0.008)***
freq4	0.935	(0.008)***	1.056	(0.009)***
freq567	1.076	(0.009)***	1.118	(0.011)***
SB × freq2	0.101	(0.015)***	0.186	(0.019)***
SB × freq3	0.099	(0.015)***	0.151	(0.019)***
SB × freq4	0.089	(0.016)***	0.116	(0.019)***
SB × freq567	0.136	(0.016)***	0.093	(0.020)***
Inland	0.426	(0.009)***	0.482	(0.009)***
lnsf	0.258	(0.027)***	0.266	(0.030)***
lnvalue	0.134	(0.019)***	0.176	(0.022)***
fixtures	0.005	(0.003)***	0.001	(0.003)***
bedrooms	0.021	(0.007)***	0.012	(0.008)***
age	0.019	(0.001)***	0.025	(0.001)***
age2	0.000	(0.000)***	0.000	(0.000)***
avgtemp	0.011	(0.002)***	0.007	(0.002)***
avgwind	-0.026	(0.011)***	-0.020	(0.013)***
maxwind	0.015	(0.004)***	0.010	(0.005)***
avgwind × SB	-0.014	(0.013)***	-0.003	(0.016)***
maxwind × SB	0.002	(0.004)***	-0.003	(0.006)***
year2010	0.530	(0.174)***	0.288	(0.215)***
freq1 × 2010	-0.004	(0.009)***	0.007	(0.011)***
freq2 × 2010	0.013	(0.009)***	0.040	(0.011)***
freq3 × 2010	0.015	(0.009)***	0.045	(0.011)***
freq4 × 2010	0.026	(0.010)***	0.063	(0.013)***
freq567 × 2010	0.006	(0.012)***	0.031	(0.015)***
SB × freq3 × 2010	-0.002	(0.033)***	-0.164	(0.041)***
SB × freq4 × 2010	-0.005	(0.034)***	-0.147	(0.042)***
SB × freq567 × 2010	-0.009	(0.034)***	-0.128	(0.042)***
avgtemp × 2010	-0.007	(0.002)***	-0.004	(0.002)***
avgwind × 2010	0.043	(0.012)***	0.051	(0.014)***
maxwind × 2010	-0.019	(0.005)***	-0.021	(0.006)***
avgwind × SB × 2010	-0.021	(0.015)***	-0.027	(0.018)***
maxwind × SB × 2010	0.009	(0.005)***	0.016	(0.006)***

\* significant at the 10% level.

\*\* significant at the 5% level.

\*\*\* significant at the 1% level.

Table E.12 depicts the full results for the RE regressions. Comparing these results to the posterior means in Table 1, we see that the RE models systematically under-estimate the incremental increase in use and peak at any frequency for SB-type weeks (variables “SB × freq2” through “SB × freq567”). Expressed in percentage terms, this bias is of considerable magnitude, ranging from 7 to 11% for use and 15 to 21% for peak.

Furthermore, the RE models estimates pure policy effects for use peak (“year2010”) that are 30–40% larger, respectively, than the small effects produced by the correlated Bayesian system.

Finally, the RE model under-estimates the reduction in peak for SB-types compared to 2008 (“SB × freq3 × 2010” through “SB × freq567 × 2010”) by approximately 5%. We thus conclude that the additional complexities in estimation from switching to a fully correlated triple-equation system are justified for our application.

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## **APPENDIX 5-3**

Enhanced Demand-Side Management

Programs and Actions



## ***Enhanced Demand-Side Management Programs and Actions***

Extended drought periods can result in severe consequences to socio-ecologic systems. As experiences in 2014 and 2015, within the TMWA service area (and most of the western U.S.), prolonged, dry hydrologic periods can occur. In order to enact policy that mitigates potential vulnerabilities to local water resources, TMWA must consider management tactics to mitigate drought periods that extend beyond those experienced over the past century (see Chapter 2 for a discussion of effects of local climate change). Should prolonged, dry hydrologic conditions persist, there are a myriad of possible programs not included in TMWA's current Conservation Plan that could be deployed to further reduce demand for water.

TMWA's Conservation Plan is oriented around efficient use by its customers **every year**. In periods of extended drought, TMWA's demand-side management programs ("DMPs") can be enhanced and oriented toward targeted reductions in monthly water use. Depending on projected use of drought reserves, TMWA first defines the target reduction needed to ensure drought reserves are adequate to serve its customers over that year and multiple succeeding years. For example, starting in May of 2015 TMWA asked its customer to reduce their water use by *at least* 10 percent compared to their monthly usage in 2013. Once a target is established, then a suite of actions that will facilitate this reduction are selected and implemented within a specified timeline. These programs and measures can have significant administration costs and lengthy timelines in order to be implemented, and/or require additional action(s) by local governments. Moreover, some actions can have adverse, long-term economic impacts to TMWA and the community at large; therefore TMWA weighs all the costs and potential benefits each action might have when creating the suite of actions it will deploy.

Conjunctive implementation of the appropriate types of actions is the key to successfully meeting the targeted water use reduction goal. Any decision on a new suite of conservation actions must also considers how interdependent individual actions can have with one another. For example, should additional watering restrictions or moratoriums be put into place, monitoring and enforcement must be enhanced to ensure compliance is met. Similarly, if rebates are considered, such as those designed to reduced turf or increase the use of water efficient technology, changes in local laws might be necessary to guarantee future development reflect the desired outcome(s) (i.e., restricting the amount of turf new properties can have or requiring the use water efficient irrigation technology).

Table 1 provides a list of various enhanced demand-side management actions ("*e*DMPs"), which, in addition to TMWA standard programs described in Chapter 5, could be deployed depending on projected use of drought reserves. The table lists qualitative estimates of the associated costs and benefit potentials based on prior studies for each *e*DMP.

Table 1: Potential Enhanced Demand-side Management Programs and Associated Costs and Benefits

Type	Action Taken	Program Costs <sup>1</sup>	Level of Effort to Implement <sup>2</sup>	Level of Customer Participation	Level of Water Savings Per Customer	Benefit Potential <sup>3</sup>
Customer Education	Information on Water Usage	Moderate	Moderate	High	Moderate	at least a 6% reduction in demand
Pricing Mechanism	Rate Schedule Adjustment (marginal increase)	Low	Moderate	High	Low	2% reduction for a 10% increase in the block rate
Pricing Mechanism	Rate Schedule Adjustment (moderate increase)	Low	Moderate	High	Moderate	2% reduction for a 10% increase in the block rate
Pricing Mechanism	Rate Schedule Adjustment (significant increase)	Low	Moderate	High	High	2% reduction for a 10% increase in the block rate
Pricing Mechanism	Seasonal Drought Rate (marginal increase)	Low	Moderate	High	Low	2% reduction for a 10% increase in the block rate
Pricing Mechanism	Seasonal Drought Rates (moderate increase)	Low	Moderate	High	Moderate	2% reduction for a 10% increase in the block rate
Pricing Mechanism	Seasonal Drought Rate (significant increase)	Low	Moderate	High	High	2% reduction for a 10% increase in the block rate
Pricing Mechanism	Violation Fines (marginal increase)	Moderate	High	Low	Low	2% reduction for a 10% increase in the block rate
Pricing Mechanism	Violation Fines (moderate increase)	Moderate	High	Low	Moderate	2% reduction for a 10% increase in the block rate
Pricing Mechanism	Violation Fines (significant increase)	Moderate	High	Low	High	2% reduction for a 10% increase in the block rate
Enhanced Metering	Daily meter reading of all customers	High	High	High	Low	Reduction potential not quantified
Enhanced Metering	Metering of all domestic wells	High	High	Low	Low	Reduction potential not quantified
Rebate	Rebate: Turf Conversion	High	High	Low	Moderate	~30% reduction in use per service
Rebate	Rebate: Efficient Irrigation Technology	Moderate	Moderate	Moderate	Moderate	20-50% improvement in irrigation efficiency
Rebate	Rebate: Low-flow Appliances	Moderate	Moderate	Moderate	Low to Moderate	High variability in savings depending on appliance
Watering Restrictions	Restrictions on Business	Moderate	Moderate	Moderate	Low	Reduction potential not quantified
Watering Restrictions	Weekly watering: 1	Moderate	High	High	Moderate	Reduction potential not quantified
Watering Restrictions	Weekly watering: NONE	Moderate	High	High	High	~75% reduction in water use per service with irrigation
Watering Restrictions	Moratorium on Car Washing	Low	High	High	Low	Reduction potential not quantified
Watering Restrictions	Mandatory Water Budgets	Moderate	High	High	Moderate to High	Reduction dependent upon budget amount
Landscape Requirements	Ordinances: Xeriscape Requirement (some xeriscape)	Moderate	Low	Moderate	High	~30% reduction in use per service
Landscape Requirements	Ordinances: Turf Requirements (no new turf)	Moderate	Low	Moderate	High	~30+% reduction in use per service
Landscape Requirements	Ordinances: Efficient Irrigation Technology	Moderate	Low	Low	Moderate to High	20-50% improvement in irrigation efficiency
Landscape Requirements	Ordinances: Certified Car Wash Program	Moderate	Low	Low	Low	Reduction potential not quantified
Landscape Requirements	Ordinances: Water Capture Requirements	Moderate	Low	Low	Low	Reduction potential not quantified
Landscape Requirements	Ordinances: Homeowner Association Restrictions (new developments)	Moderate	Low	Low	High	~30% reduction in use per service
Landscape Requirements	Ordinances: Homeowner Association Restrictions (all developments)	Moderate	Low	Moderate	High	~30% reduction in use per service

1. Cost includes but is not limited to increases in number of personnel, vehicles, IT support, messaging/advertising, local entity enforcement, or administrative support.

2. Level of effort to implement includes but is not limited to how/type/frequency of messaging/advertising delivered, numbers of personnel required to deploy, public hearings, community resistance.

3. Benefit potential is based on results from previous studies.

## *Customer Education*

Information on Water Usage. Information can be a very powerful tool to help consumers make more informed decisions. Different types of information can be used to promote additional customer savings in various ways including: cost-saving information, targeted analytics, and social norms persuasion. As of the writing of this WRP, TMWA is engaged in a sample study to determine the effect of several informational products on customer water conservation, in order to determine if such programs are effective means of conservation during droughts.

- Cost-saving Information. Educating customers about water waste has been a major part of TMWA's past conservation efforts. In the future, customers can be provided with even more specific information on the cost-saving nature of different water saving practices.
- Targeted Analytics. Providing customers with tailored information regarding their water use can be a power mechanism for changing water usage behavior. Highly customized informational products gives customers' knowledge beyond their monthly usage by providing daily usage, comparing current usage to past usage, and indicating whether customers have met any established conservation goals. This knowledge gives customers a great ability to identify where they can alter their behavior to use water more efficiently.
- Social Norms Persuasion. Customers can also be supplied with information about how their usage compares with similar properties in their neighborhood. Research has suggested that such "social pressure" leads many above-average water users to conserve more water in order to better fit in with their neighborhood.

## *Pricing Mechanisms*

Rate Schedule Adjustment. Water rates provide a pricing signal to customers so that they use water efficiently. For example, in the TMWA service area, on average, customers who converted from a monthly-flat-rate schedule to a metered rate reduced their water consumption by 39 percent. Moreover, a reduction in usage was seen in both indoor water use, as well as, outdoor use, indicating many aspects of the customer's water usage behavior were altered toward more efficient use. Since increasing water rate prices is a market-based approach to water reduction, it implies reductions are voluntary. A customer decides how much he/she wants to conserve based on their bottom line. A study conducted by the Economics Department at the University of Nevada on single-family metered water user in Washoe County indicates that a 10 percent increase in metered rates is associated with a two percent decrease in water use, on average (Lott et al. 2013). Currently TMWA only adjusts rates in order to meet the cost of service, which requires an in-depth cost of service study. However, TMWA could evaluate rate adjustments as a method to conservation without creating negative impacts to its revenues.

Seasonal Drought Surcharge. A drought surcharge could be a potential method to encourage enhanced water conservation. Like rate adjustments, a drought surcharge is a market-based approach meaning any water conservation as a result is voluntary. A drought surcharge is an adjustment that is temporary as it only applies during periods when TMWA must use storage

reserves to meet demands (typically during the irrigation season). Once the system's reserves are reestablished, the drought surcharge is lifted and prices would return to the normal rate schedules. Due to this flexibility, it can be seen as a more attractive option than a permanent rate increase to reduce water demand. A drought surcharge is also flexible in that it can have a variety of different structures, i.e., it can be a flat surcharge, a variable surcharge based on the percentage of use, or can be integrated directly into the tiered rate schedule (i.e., applied only to certain blocks of water use). A well-thought out drought surcharge structure has to consider ease of implementation, customer classes affected, equity within and between customer classes, and the long-term consequences to demands and revenues.

Water Violation Penalty Adjustment. Preliminary analysis on TMWA's Water Watcher program indicates, on average, residential customers who were issued a penalty for water waste violations *did not* decrease water consumption after the fine was issued. In some cases residential violators increased use after a penalty was issued. Results indicate residential violators are typically wealthier and live on larger lots compared to TMWA's typical residential customer. The current penalty schedule's fee structure likely does not prohibit water violations because of the average socio-economic status of the offenders (i.e., the penalty amount may be perceived as nominal). Increasing the amount a violator would pay would provide more of a monetary incentive to abide by TMWA's water usage regulations. Penalty adjustments could be made depending on the severity of the violation and the severity of drought periods. The inclination for TMWA to issue a penalty (as opposed to taking other, non-punitive measures) could also be directly correlated to any additional water use restrictions, such as watering day restrictions, moratoriums on car washing, etc. To determine an optimal water violation penalty structure that would achieve the desired results, more analysis about how the penalty structure alters the customers' propensity to save water is warranted.

## ***Rebates***

Turf Conversion. Turf-dominated properties use approximately four times more water than xeriscaped properties. Replacing turf with a more water-conscious landscape is a method for long-lasting water conservation. A turf conversion rebate program incentivizes residents to replace their turf by offsetting the cost of re-landscaping by providing a rebate based on the per-square-foot amount of lawn removed. Some studies on turf conversion programs indicate a residential customer can reduce his/her water consumption by approximately 30 percent. The main reason such a program can be effective is because it usually implies a more efficient irrigation system is used (i.e., a sprinkler-dominated irrigation system often is converted to drip-dominated system). Turf conversion programs are typically implemented by the water purveyor or water-controlling municipality using funds from new development fees, customer rate revenues, or local/state grants. In order to have a significant effect of reducing water consumption, tens of millions of square feet of turf must be converted at costs in the tens of millions as well. In addition to the total cost of the rebates, administrative costs are associated with the program's implementation and oversight including the application process, rebate administration, and compliance checks.

Efficient Irrigation Technology. Overuse of water in irrigation is due, in part, to inefficiencies in the water delivery system. Since irrigation controls are predominately automated, once water

timers are set, they are often forgotten about. However, over the irrigation season precipitation and/or wind events can occur during watering times. Unless the customer is able to manually adjust timers accordingly, the result is the application of water when irrigation is not necessary or highly inefficient. Many of the existing irrigation controllers utilize technology that predate the era of “smart” devices. High efficiency irrigation technology such as “smart” controllers can make real-time adjustments to irrigation schedules based on weather information, saving 20-50 percent of the water relative to standard controllers. Such technology is ideal for commercial applications because it eliminates the need for travel to multiple controller sites. The downside to “smart” controllers is the cost. For commercial applications when considering the saving in the monthly water bill and labor costs associated with manually changing watering schedules, savings could be achieved in as little as one irrigation season. A cheaper alternative to the “smart” controller is a rain sensor. Like the “smart” controller, a rain sensor will prohibit watering during precipitation events. For residential applications, this technology could be preferable since it is a fraction of the cost of “smart” controllers. A program that provides rebates for purchases of “smart” irrigation controllers or rain sensors could help replace older technology and increase irrigation efficiency on existing residential and commercial properties. Unlike, turf conversion rebate programs, these rebate programs would require substantially less funding and administrative oversight overall. Such automatic changes in watering times can conflict with assigned watering day schedules, so variances for watering during off-schedule times should be considered along with the accompanying administrative cost to manage those with variances.

Low-Flow Appliances. As with irrigation technology, many existing homes that predate enhanced standards in plumbing codes have appliances (e.g., toilets, dishwashers, washing machines, etc.) that are considered inefficient by current standards. For example, dishwashers made before 1994 use ten gallons more water than modern dishwashers. New, water-efficient toilets can provide overflow prevention and leak detection, and use approximately 20 percent less water than the standard 1.6 gallons per flush toilets. Similarly, water-efficient washing machines use up to 50 percent less water than older machines. A program that provides rebates for purchases of water-efficient appliances could incentive some customers to replace existing inefficient appliances. This would lower indoor water consumption overall, as well as, reduce peak day demands. However, the overall effectiveness of the program relative to the total cost to TMWA must be considered. Indoor use only account for a small percentage of monthly water use during periods of drought when reserves are be used. If the goal is to target reduced use during periods of drought, this option might not be as effective as other options. If the goal is a campaign to reduce water usage long-term, then such an option might be practical.

### ***Enhanced Metering***

Daily Metering of All Customers. Currently the majority of meters on TMWA’s service connections provide readings on water usage aggregated at the monthly level (approximately 23 - 37 days). However, new water meter technology allows for the collection of daily meter readings. Water measurement at this level of granularity would provide TMWA with information that would be helpful in identifying more water violations (i.e., irrigating on incorrect days or incorrect times), the ability to provide better information on customer water use (e.g. targeted analytics), as well as, the ability to notify customers of potential leaks in real-time. This level of

monitoring would ensure water efficient behavior is consistent across the TMWA service area. Given that the majority of TMWA service connections do not have this type of meter installed, a retrofit program to switch out the existing meters would be in the millions of dollars range over a multi-year timeline.

Metering of Domestic Wells. While TMWA provides meters for all its service connections, properties that obtain water from domestic wells do not have meters to track groundwater pumping. While these individuals are not TMWA customers, they share the same groundwater resources and therefore should conserve water like the rest of the community. In order to monitor private groundwater extraction, meters could be installed on all domestic wells. Such an action would require statutory change in the NRS and a method of funding the program.

### ***Water Restrictions***

Restrictions on Businesses. Should drought periods persist and a state of emergency be declared in Washoe County, TMWA could ask all businesses within the food industry serve all items on paper plates and provide disposable utensils in order to remove the need to wash dishes. As well, TMWA could ask that all cleaning services utilize cleaning products that don't require water. Within the hotel industry, TMWA could be asking that establishments restrict their laundry services to only what is absolutely necessary. TMWA could also place restrictions on water used in fountains and water features. While these actions would reduce commercial demand, in order to comply such restrictions could place additional financial stress on businesses. For compliance to be uniform, additional monitoring and enforcement mechanisms would need to be in place.

Moratorium on Washing Cars. In the event that a drought emergency is declared, TMWA could place restrictions on using potable water to wash cars, restricting the activity to only commercial car wash businesses that have a certified water reclamation system. Customers caught violating this requirement would be fined accordingly; such as action would require additional monitoring and enforcement to ensure compliance.

Mandatory Water Budgets. Currently, all conservation by TMWA customers is strictly voluntary. However, should extended drought periods persist; all customers could be given individualized water budget (i.e., a set amount that may be used within a month). Should a customer exceed the budgeted usage specified, a penalty surcharge could be incurred. Individualized water budget amounts could be estimated based on historic averages for each service connection and scaled down to achieve a targeted reduction goal. Implementation of individualized water budgets would be a long process. Increased communication and educational programs would be necessary to inform customers of the change. There is a potential for an impact TMWA's revenue stream which could result in a dramatic increase in the cost customers pay for water.

Once-Per-Week Watering. In the event that a drought emergency is declared, TMWA could change the three-day-a-week water schedule to a once-per-week watering scheduling. Customers caught violating this requirement would be fined accordingly. This action could drastically

reduce water usage but could result in adverse consequences including a spike in peak day usage, severe overwatering, and damage to property owners' landscaping.

Moratorium on All Outdoor Watering. In the event that a drought emergency is declared, TMWA could place a temporary moratorium on *all* outdoor watering. Customers caught violating this requirement would be fined accordingly. Since irrigation uses the majority of the water used by a service during the warmer months, this actions would ensure adequate drinking water is available during that time. However, the impacts to TMWA's revenue stream could result in a dramatic spike in the cost customers pay for water. Furthermore, this action could result in irreparable damage to property owners' landscaping causing widespread economic losses.

### ***Landscape Requirements***

The next water conservation programs discussed below *are not* actions TMWA could take directly to promote conservation. However, in the past TMWA has worked with local municipalities to promote water-conscious local ordinance. The following paragraphs discuss potential water saving actions local municipalities can take with respect to future development. The savings such actions would have vary depending on the number of properties which would be impacted by the changes.

New Development Landscape Requirements. Turfed landscape is often over-watered and prone it inefficient irrigation (over-spray, evaporation loss, etc.), with as little as 40 percent of the water that is applied to turfed areas actually being used by the grass. Within TMWA's service area, local municipal ordinances dictate minimum amounts of turfed area properties must have (based on jurisdiction and zoning district). As the region grows and new developments are established, these ordinances could be amended to set limits on the maximum amount of turf a new property could have. Ordinances could also prohibit the laying of sod or planting of new grass seed during drought periods. If drought periods persist indefinitely, a moratorium on any new turfed areas could be implemented as a last resort. Such amendments to local ordinances could be paired with a rebate program for existing property owners, in order to gain maximum effectiveness.

Xeriscape requirements. Studies have indicated xeriscape is a water-conserving alternative to turf. Drought-tolerant vegetation (often native plants) can survive on less water (approximately 30 percent less than turf) and often become dormant (i.e., do not grow) during the hottest part of the summer. Currently, while local ordinances encourage the use of drought-tolerant landscape practices, none require xeriscaping on properties. Landscape ordinances could be amended to require the use of drought-tolerant plants for new buildings and minimum areas of xeriscape could be specified to ensure the majority of new landscaping is water-conscious.

Efficient Irrigation Technology requirements. As discussed previous in the Rebates section, new technology on efficient irrigation systems is readily available. Landscaping ordinances could be amended to require the use of "smart" controllers in all new commercial buildings and rain sensors in all residential developments. Such amendments could be paired with a rebate program for existing commercial and residential owners in order to gain maximum effectiveness.

Water-Capture Device Requirements. During precipitation events most of the water that falls on impervious surfaces is channeled to storm drains and eventually to the Truckee River. While significant rainstorms are not common in Washoe County, some climate change predictions indicate rain will become more frequent in the future. Water capturing devices such as rain barrels and onsite storage tanks can capture rain water to be used in irrigation at a later date. While retrofitting existing building with such devices would be relatively cost-prohibitive, amending building codes to require the installation of water-capture devices on new buildings and residences could reduce the amount of water required on a given property. Similarly, much of the water used inside a building is not consumed and could be reused onsite. This “gray water” that results from washing, cleaning, and similar activities could be recycled and used on irrigation. This action not only would conservation the amount of potable water supplied to services, but would also lower the amount of water (and associated costs) the Truckee Meadow Water Reclamation Facility would have to process. The benefits of such a requirement depend heavily on the amount of rainfall expected over time. Should rain events become more commonplace, such a requirement could help lower demand for potable water.

Certified Car Wash Program. Practices within the car wash industry vary. Standards on high pressure nozzles, water capture and disposal systems, and leak detection can change from business to business. In order to ensure the highest standard for water conservation is achieved uniformly, municipalities could partner with the local car wash industry to develop a water-saving car wash standardization program that identifies Best Management Practices. A provision that requires all businesses within the car wash industry adhere to these practices would ensure compliance is met.

Homeowner Associations Restrictions. Currently, rules and regulations within private agreements for residential planned unit developments (“PUD”) supersede city and county landscaping ordinances. Private agreements under Homeowner Associations can either help or hinder efforts by restricting how occupants can manage their properties. Approval of future developments could require all private agreements associated with PUDs are consistent with municipal ordinances regarding water conservation and landscaping requirements. Allowing property owners under current private agreements the option to convert existing turf on their landscape to a water conserving alternative would facilitate an even greater reduction in water usage. Per NRS 116.330 property owners have the right to install or maintain drought tolerant landscaping on their properties so long as it is compatible with the community design and is approved by the governing body. Local government entities could work with Homeowners Association to ensure such transitions could be made by residents on existing properties whom are interested in doing so.

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