Home Next

Inexpensive, High Resolution Data for Quantifying Water Use, Conservation, and Differences by Gender

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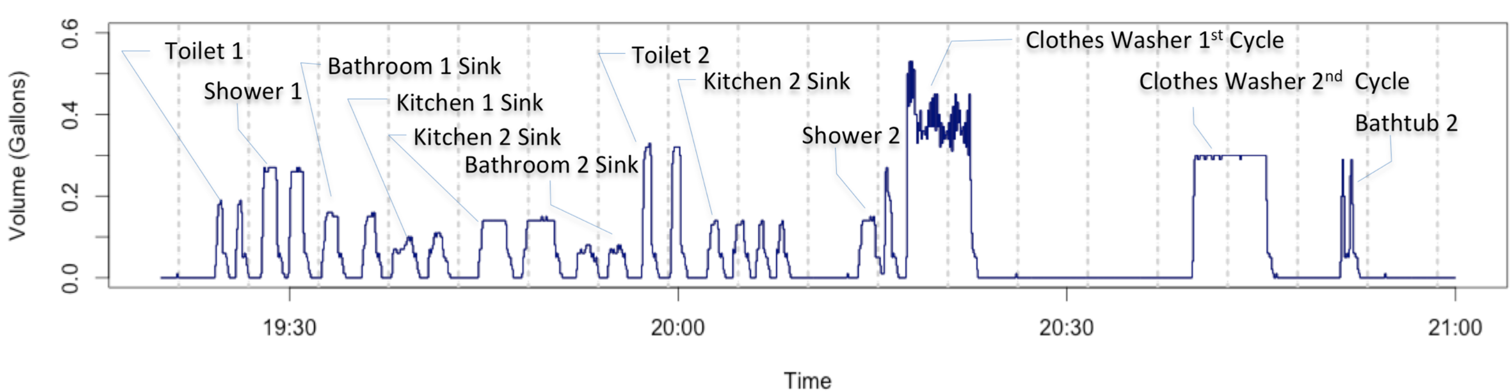
COLLEGE of ENGINEERING
UtahStateUniversity

Civil & Environmental ENGINEERING

Navigation

Introduction

- Innovations in smart metering are being driven by needs to evaluate water demands for individual end users and end uses
- With the increasing interest in water conservation programs, measuring and managing indoor water use has become an important research topic
- Fine temporal and spatial resolution can help managers
    - Isolate end uses
    - Better understand the quantity and timing of water use
    - Identify opportunities for savings



A sample water use trace for a typical residential home showing individual end uses.

The Problem

For large institutions, water use is a significant cost

Utah State University

- > 27,000 students (includes regional campuses)
- > 800 Faculty members
- > 1600 Staff members

UtahStateUniversity

USU is effectively a small city, with all of the same challenges in providing a safe and adequate water supply.

- A lot of smart metering work has been done for more traditional, residential water use monitoring
- Less work available for larger, institutional users

The Problem

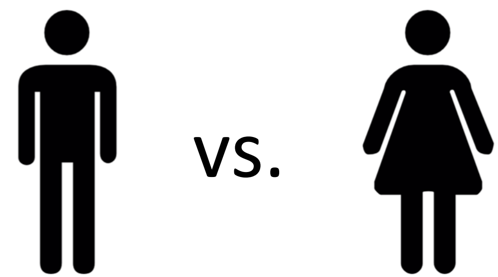
How can we examine institutional water use and look for opportunities to save?

- For many institutional buildings, there may be no ongoing monitoring
- Where monitoring is ongoing, it is often conducted at too aggregate a level
  - A single meter for an entire building
  - Larger meters cannot always resolve smaller flows
  - Too coarse of a temporal or spatial scale to reveal water use behaviors

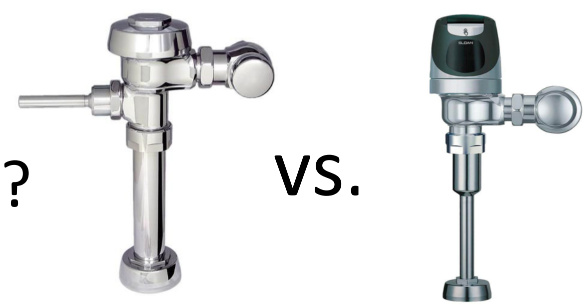
Research Questions

1. How can we quantify water use and behavior in high-traffic university facilities and identify potential water savings after installing high efficiency water fixtures?

2. How can we estimate individual water use and potential gender differences?

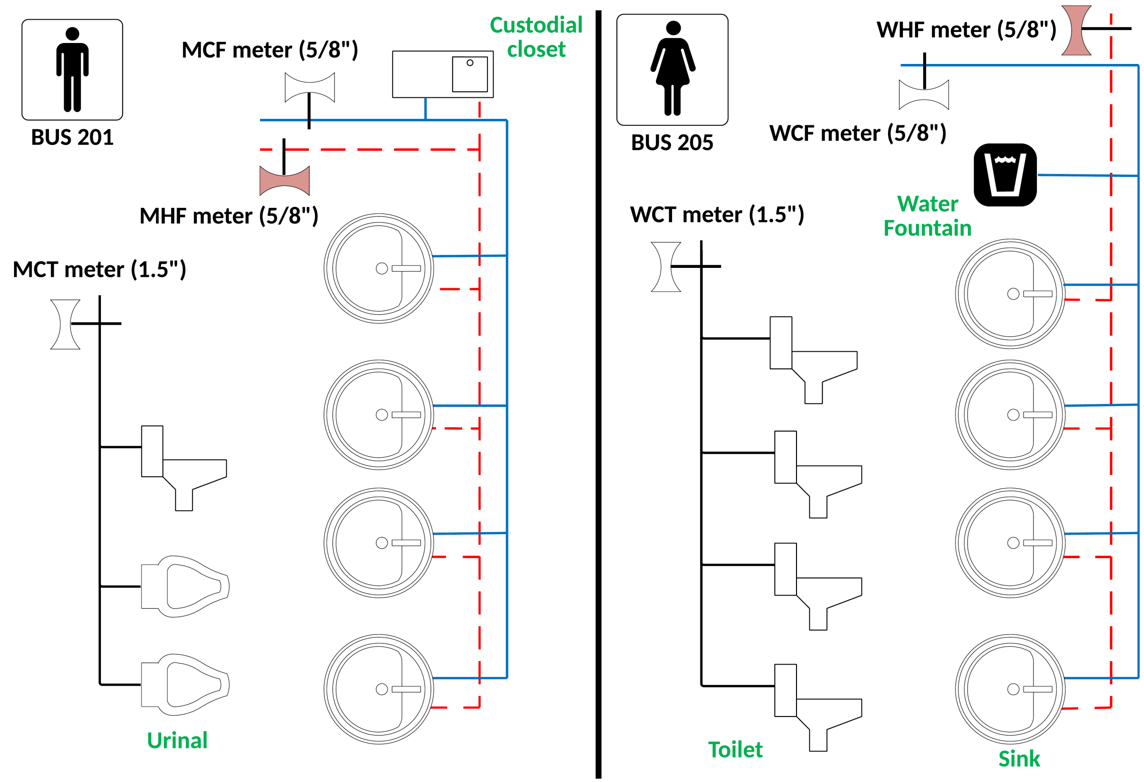


3. How can we verify manufacturer specifications of expected fixture performance by metering water usage?



Methods
Study Area

- Utah State University Business Building
- Men's and Women's restrooms
- Pre and post retrofit with automated (motion controlled) toilet flush valves and faucets



Manufacturer's specifications for restroom water fixtures.

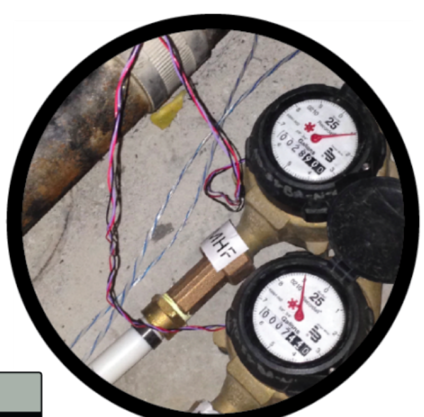
Restroom	Quantity	Fixture	Pre- retrofit Kohler/Manual		Post-retrofit Kohler/Automatic	
			Flowrate (gpm)	Volume (gpf)	Flowrate (gpm)	Volume (gpf)
Men	1	Toilet	25	1.6	25	1.6
	2	Urinal	10	0.125	10	0.125
	4	Faucet	2		0.5	
Women	4	Toilet	25	1.6	25	1.6
	4	Faucet	2		0.5	

Each restroom had an average of ~500 users per day

Methods – Water Meters

- 3 meters per restroom:
  - Hot water supply (sinks)
  - Cold water supply (sinks)
  - Cold water supply (toilets/urinals)
- Standard positive displacement meters – common for residential/low flow applications
- “Nutating” disks with coupled magnets

Neptune T10

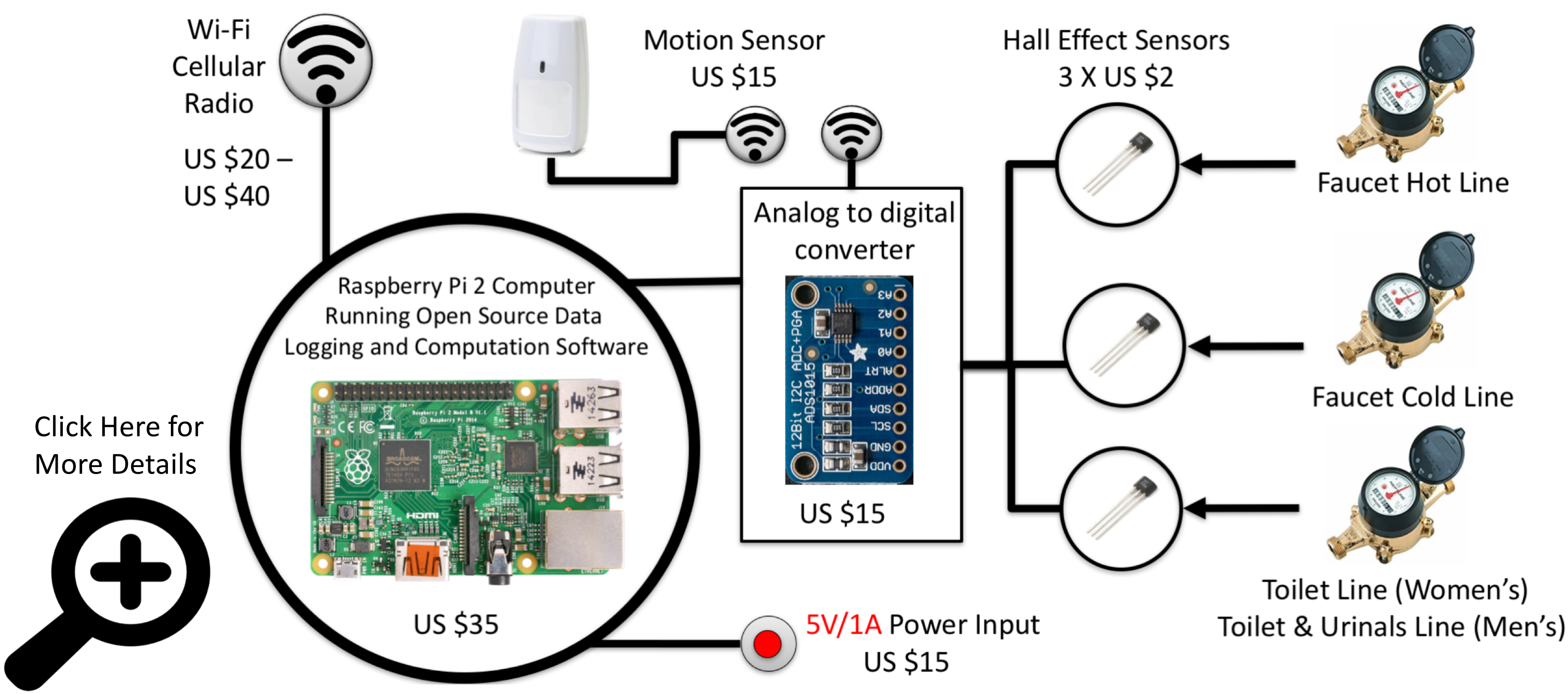


Badger Meter Model 25 Recordall

Methods
Data Collection Platform

- Hall effect sensor for counting “nutations”
- Motion sensor for counting restroom users
- Logging using a Rasberry Pi computer
- Calibrated in USU’s hydraulics lab prior to installation
- WiFi connected for remote data download

Total Cost: ~$100 – $150 US



Methods – Data Collection

- Raspberry Pi computer programmed as a datalogger:
  - Counted individual meter “nutations” as magnetic pulses
  - Counted motion sensor pulses as restroom users
- Data recorded at ~4 s frequency
- Data collected for approximately 2 weeks before and after retrofit with automated fixtures

```
Datalogger Name: Raspberrypi04
Site Name: Business Building Men's Restroom
Site Description: Men’s restroom – room BUS 201 on USU’s Logan campus.
TIMESTAMP,RECORD,MEM_SPACE_AVAILABLE,PeopleCounter,MHF_rev,MCF_rev,MCT_rev
2015-02-23 13:47:05.811351,177,3493756928,1,0,0,0
2015-02-23 13:47:09.837477,178,3493756928,0,0,0,0
2015-02-23 13:47:13.862543,179,3493756928,0,0,0,0
2015-02-23 13:47:17.885878,180,3493756928,0,0,0,0
2015-02-23 13:47:21.913220,181,3493756928,0,0,0,0
2015-02-23 13:47:25.942054,182,3493756928,0,0,3,0
2015-02-23 13:47:29.970999,183,3493756928,0,0,3,0
2015-02-23 13:47:33.999984,184,3493756928,0,0,3,0
756928,0,0,2,0
756928,0,0,1,0
756928,0,0,0,0
```

User enters restroom

Cold faucet use event

Data available in HydroShare

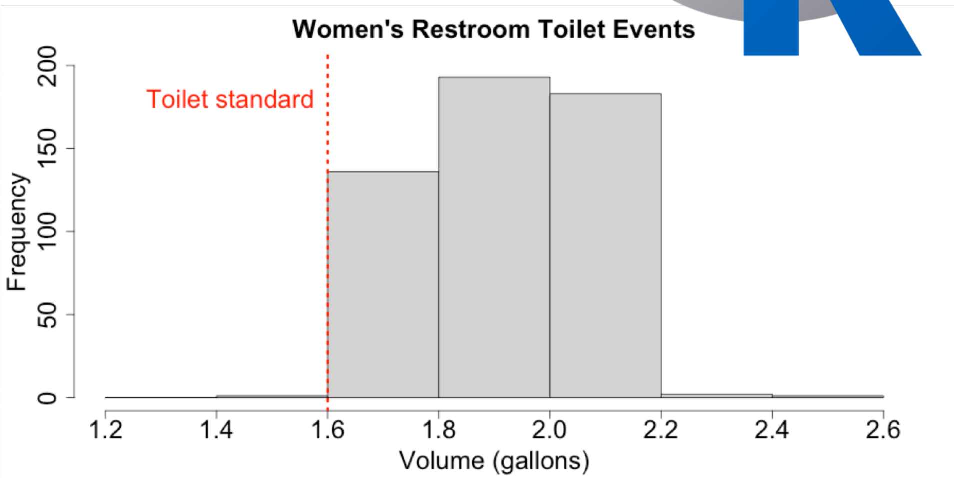
Methods – Data Analysis

- Calculated toilet and faucet flow rates from the number of recorded nutations
- Identified individual toilet events using peaks and beginning and end of non-zero values
- Disaggregation of toilets versus urinals in the men’s restroom based on volume and duration

```
# Plot a histogram for the volumes of the
tiff(filename = "Figure7a.tiff", width =
par(mar=c(4.55,4.75,3,2.5) + 0.1)
hist(WToilet_Events_Sub, xlab = "Volume (
     col = "light grey", xlim = c(1.2, 2.
     cex.main = 2, cex.lab = 2, cex.axis
```

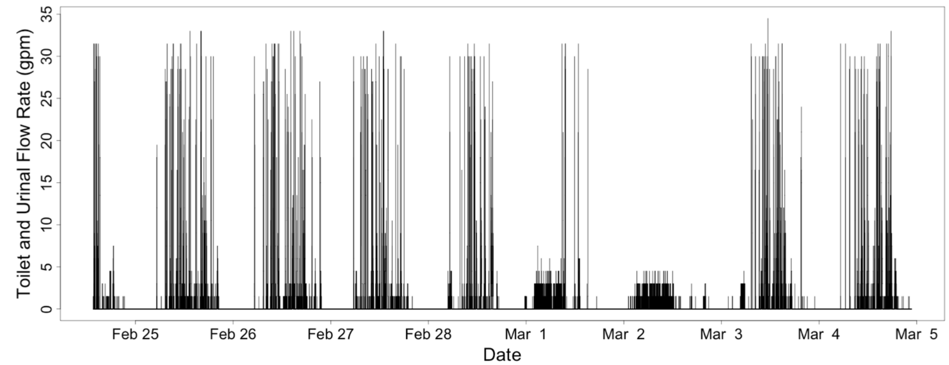
Code is available in HydroShare

HYDROSHARE



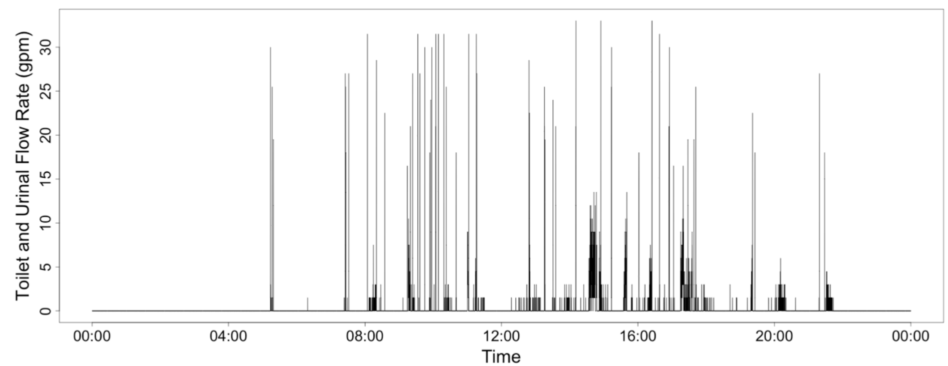
Results – Data

One week



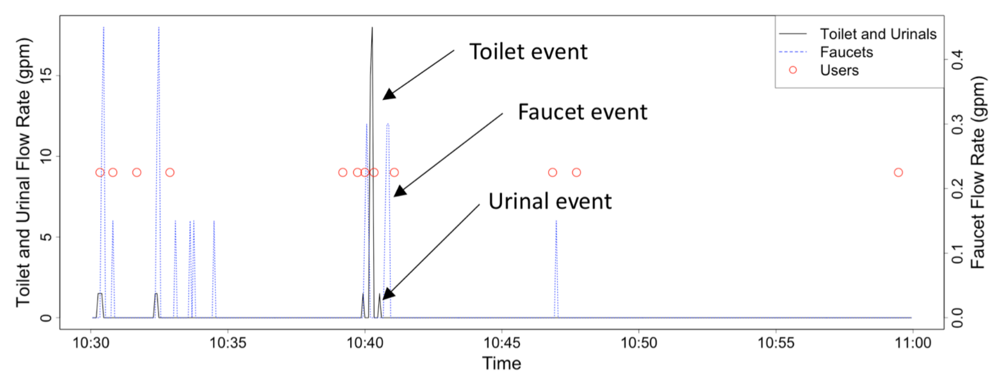
(a)

One day



(b)

30 minutes



(c)

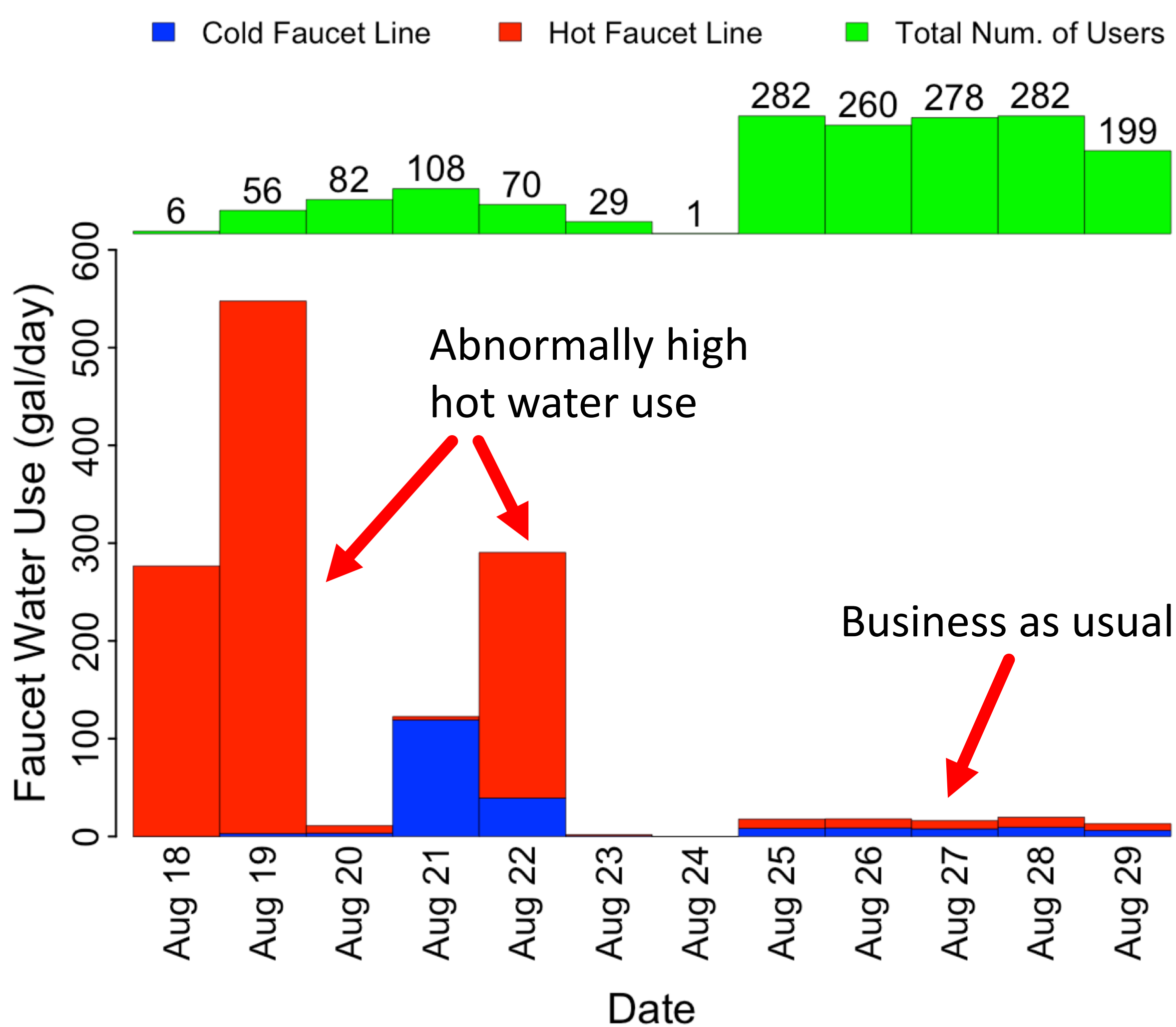
Results – Water Use

End use water savings comparison before and after retrofitting restrooms of the study sites. This table shows the average per visit water use by gender for each fixture.

Fixture	Before Retrofit (gallons per visit)	After Retrofit[a] (gallons per visit)	% Savings
Men's Restroom			
Faucet-hot	0.055	0.050	9.1
Faucet-cold	0.022	0.022	0.0
Toilet and Urinal	1.360	1.432	−5.3
Men's total	1.437	1.504	−4.7
Women's Restroom			
Faucet-hot	0.053	0.032	39.6
Faucet-cold	0.140	0.069	50.7
Toilet	2.613	2.225	14.8
Women's total	2.806	2.326	17.1

Results – Anomaly Detection

- We detected a significant leak in the men's restroom post retrofit
- USU's facilities fixed the issue, resuming normal operation
- The baseline of sampling we established helped us with identification



Results – Toilet Operation

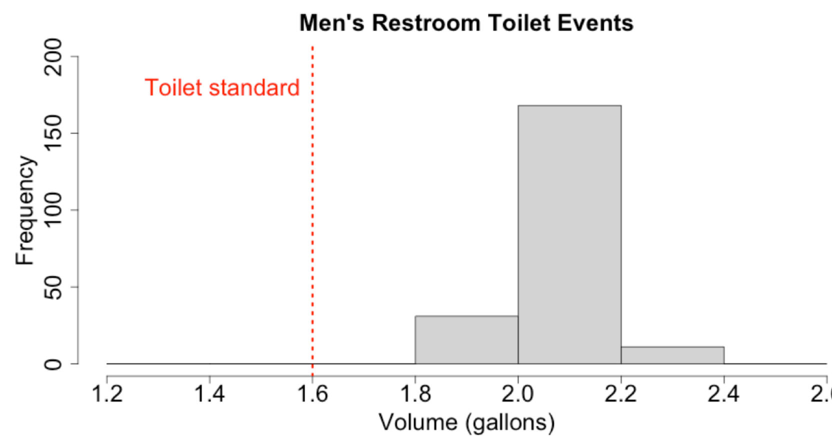
Why didn't we save more water after retrofit?

Kohler Toilets Flush Specification = 1.6 gal/flush

Before Retrofit

Mean = 1.65 gal/flush

After Retrofit



Mean = 2.12 gal/flush

- We unsuccessfully attempted to get USU facilities to install lower volume toilets
- Post retrofit toilets significantly exceeded manufacturer specifications
- Similar result in both restrooms

See more post retrofit data

Results – Estimating Water Savings

- Based on our observations:
  - Toilets in both restrooms exceeded manufacturer specifications
  - Faucet flow rates were less than manufacturer specifications
- Simulating 500 hypothetical users of the men's restroom:

Fixture	Water Use Based on Manufacturer Specifications (gal)	Water Use Based on Measured Rates (gal)
Toilet	112	159
Urinal	55	80.1
Faucet	62.5	56.3
Total	230	295

Assumptions:
- Toilet and urinal flush rates were similar to what we observed in the data
- Duration of faucet use was 0.25 min per user

- *Calculating water savings based on manufacturer specifications will significantly overestimate actual savings*
- *Actual data verify performance of fixtures*

Conclusions

- We demonstrated an inexpensive metering solution capable of collecting high resolution data
- Automated fixtures reduced overall water use by women by ~17% but increased use by men by ~4.7%
- Faucets performed at or below manufacturers specifications, but automatic toilets and urinals exceeded manufacturer specifications
- This type of data can be used to identify opportunities for conservation, prioritize upgrades, and verify performance

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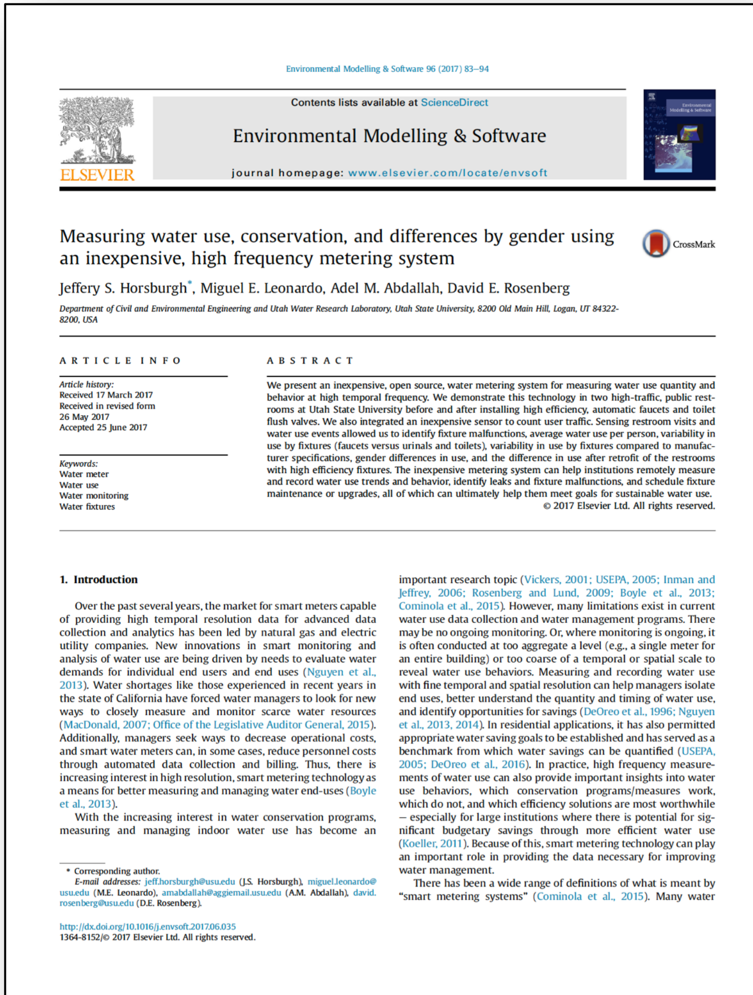
Prev.

Home

Check out the paper!



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Measuring water use, conservation, and differences by gender using an inexpensive, high frequency metering system

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ABSTRACT

We present an inexpensive, open source, water metering system for measuring water use quantity and behavior at high temporal frequency. We demonstrate this technology in two high-traffic, public restrooms at Utah State University before and after installing high efficiency, automatic faucets and toilet flush valves. We also integrated an inexpensive sensor to count user traffic. Sensing restroom visits and water use events allowed us to identify fixture malfunctions, average water use per person, variability in use by fixtures (faucets versus urinals and toilets), variability in use by fixtures compared to manufacturer specifications, gender differences in use, and the difference in use after retrofit of the restrooms with high efficiency fixtures. The inexpensive metering system can help institutions remotely measure and record water use trends and behavior, identify leaks and fixture malfunctions, and schedule fixture maintenance or upgrades, all of which can ultimately help them meet goals for sustainable water use.

1. Introduction

Over the past several years, the market for smart meters capable of providing high temporal resolution data for advanced data collection and analytics has been led by natural gas and electric utility companies. New innovations in smart monitoring and analysis of water use are being driven by needs to evaluate water demands for individual end users and end uses (Nguyen et al., 2013). Water shortages like those experienced in recent years in the state of California have forced water managers to look for new ways to closely measure and monitor scarce water resources (MacDonald, 2007; Office of the Legislative Auditor General, 2015). Additionally, managers seek ways to decrease operational costs, and smart water meters can, in some cases, reduce personnel costs through automated data collection and billing. Thus, there is increasing interest in high resolution, smart metering technology as a means for better measuring and managing water end-uses (Boyle et al., 2013).

With the increasing interest in water conservation programs, measuring and managing indoor water use has become an important research topic (Vickers, 2001; USEPA, 2005; Inman and Jeffrey, 2006; Rosenberg and Lund, 2009; Boyle et al., 2013; Cominola et al., 2015). However, many limitations exist in current water use data collection and water management programs. There may be no ongoing monitoring. Or, where monitoring is ongoing, it is often conducted at too aggregate a level (e.g., a single meter for an entire building) or too coarse of a temporal scale to reveal water use behaviors. Measuring and recording water use with fine temporal and spatial resolution can help managers isolate end uses, better understand the quantity and timing of water use, and identify opportunities for savings (DeOreo et al., 1996; Nguyen et al., 2013, 2014). In residential applications, it has also permitted appropriate water saving goals to be established and has served as a benchmark from which water savings can be quantified (USEPA, 2005; DeOreo et al., 2016). In practice, high frequency measurements of water use can also provide important insights into water use behaviors, which conservation programs/measures work, which do not, and which efficiency solutions are most worthwhile — especially for large institutions where there is potential for significant budgetary savings through more efficient water use (Koeller, 2011). Because of this, smart metering technology can play an important role in providing the data necessary for improving water management.

There has been a wide range of definitions of what is meant by "smart metering systems" (Cominola et al., 2015). Many water

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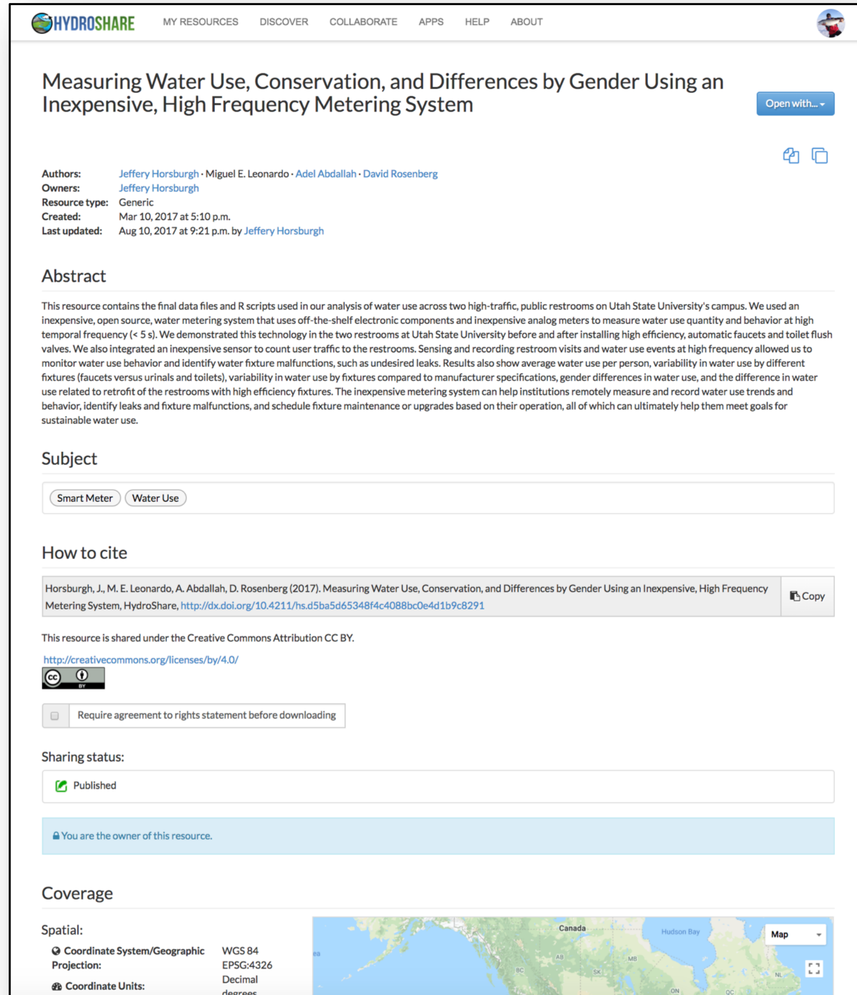
Access the code and data!



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Measuring Water Use, Conservation, and Differences by Gender Using an Inexpensive, High Frequency Metering System

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Owners: Jeffery Horsburgh
Resource type: Generic
Created: Mar 10, 2017 at 5:10 p.m.
Last updated: Aug 10, 2017 at 9:21 p.m. by Jeffery Horsburgh

Abstract

This resource contains the final data files and R scripts used in our analysis of water use across two high-traffic, public restrooms on Utah State University's campus. We used an inexpensive, open source, water metering system that uses off-the-shelf electronic components and inexpensive analog meters to measure water use quantity and behavior at high temporal frequency (< 5 s). We demonstrated this technology in the two restrooms at Utah State University before and after installing high efficiency, automatic faucets and toilet flush valves. We also integrated an inexpensive sensor to count user traffic to the restrooms. Sensing and recording restroom visits and water use events at high frequency allowed us to monitor water use behavior and identify water fixture malfunctions, such as undesired leaks. Results also show average water use per person, variability in water use by different fixtures (faucets versus urinals and toilets), variability in water use by fixtures compared to manufacturer specifications, gender differences in water use, and the difference in water use related to retrofit of the restrooms with high efficiency fixtures. The inexpensive metering system can help institutions remotely measure and record water use trends and behavior, identify leaks and fixture malfunctions, and schedule fixture maintenance or upgrades based on their operation, all of which can ultimately help them meet goals for sustainable water use.

Subject

Smart Meter | Water Use

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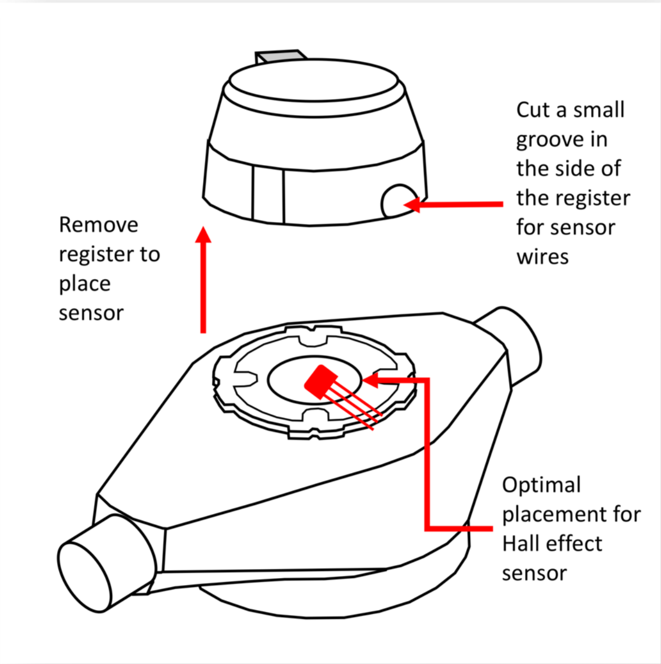
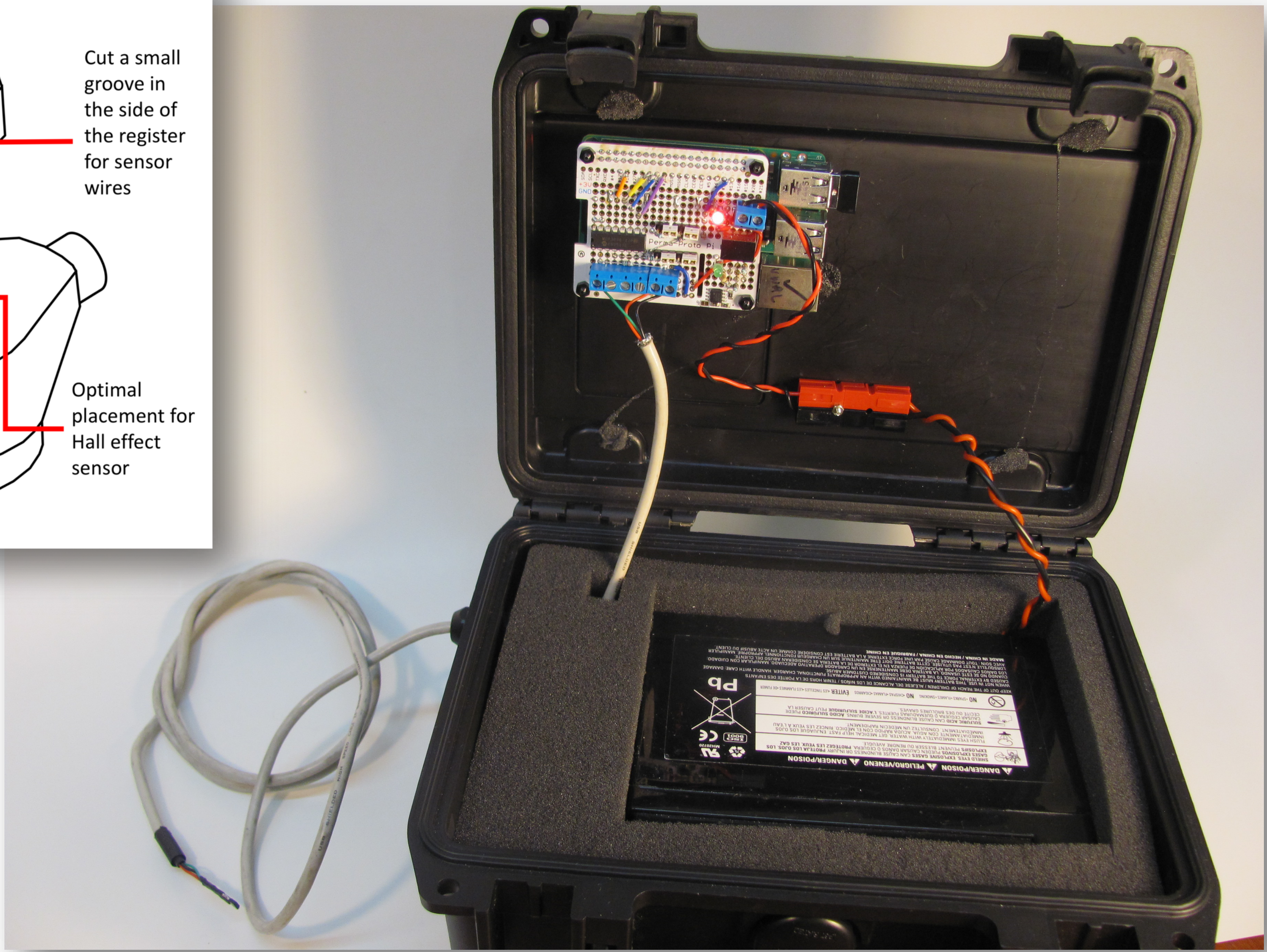
Home

Data Collection Platform





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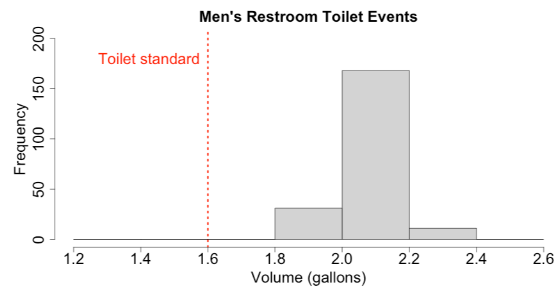
Post Retrofit Fixture Performance

Home

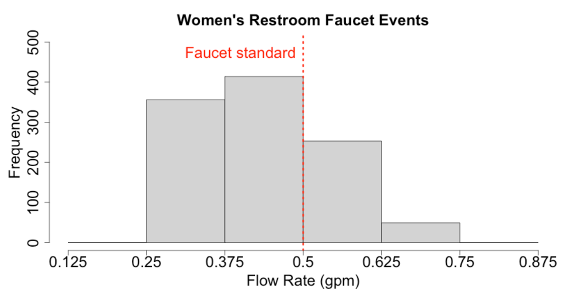
Women's Restroom

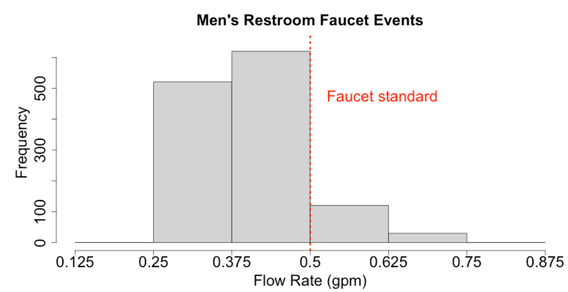
Men's Restroom

Toilets

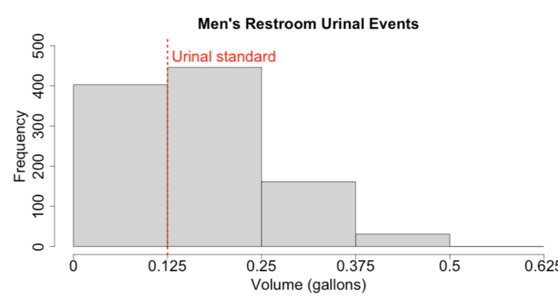


Faucets





Urinals



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