DEMAND DISAGGREGATION FOR NON-RESIDENTIAL WATER USERS IN THE
CITY OF LOGAN, UTAH, USA

by

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ABSTRACT

Demand Disaggregation for Non-Residential Water

Users in the City of Logan, Utah, USA

by

Nour M. Attaallah, Master of Science
Utah State University, 2018

Major Professor: Dr. David E. Rosenberg
Department: Civil and Environmental Engineering

Nearly all urban water use monitoring, modeling, and conservation research has focused on a large but relatively homogenous group of residential water users. Although non-residential business and commercial establishments, industries, and institutions use significant volumes of water, their diversity has made them difficult to monitor and study because their water use varies in terms of amount, timing, location, and other factors.

With the emergence of newer “smart” meters, water use now can be measured and recorded at a very high temporal frequency. Smart meters can help determine total water use, timing, and component end uses to better understand current water use practices by non-residential users.

Starting from the monthly billing data provided by the City of Logan, UT, we solicited six users to participate in this study. Old water meter registers for the
selected participating facilities were replaced with new ones that read water use at a 5-minute frequency. Additional data loggers were attached to the newer registers to read data with a 5-second frequency. Water use data were collected from the deployed smart meters over the period between August 2017 and June 2018. This was the longest period recording high frequency data of water use to date.

Without the need for installing individual meters for every water end use, we identified different water use events, average water use per end use, variability in end uses (faucets/toilets versus showers), variability in use by the type of user (manufacturing versus assisted care facilities) and the potential signature of different fixtures.

We validated our findings with the feedback from participating businesses’ representatives where we inspected whether the results matched the expected water use behavior of the business.

We applied the Gallons Per Capita Day (GPCD) method to investigate the water use behavior of non-residential users and compared it to residential users. We investigated the diurnal water use patterns and trends for the participating facilities, where we found that users exhibited heterogeneous water use patterns. Finally, we recommend some conservation actions for the participating facilities of this study. The findings from this research can help the water managers in Logan City with better understanding of commercial, industrial, and institutional (CII) water use behavior and an insight for future water supply planning for the CII sector.
PUBLIC ABSTRACT

Demand Disaggregation for Non-Residential Water Users in the City of Logan, Utah, USA

Nour M. Attaallah

Non-residential users contribute to a significant portion of the total water delivered by water supplying agencies. However, a very limited number of studies have attempted to investigate the water use behavior of non-residential users. With the emergence of newer “smart” meters, water use now can be measured and recorded at a very high temporal frequency. Smart meters can help determine total water use, timing, and component end uses to better understand water use practices by non-residential users.

Water end use disaggregation is the process of separating the water used by each fixture or process within a facility. This is useful because having a breakdown of the consumption of all end uses may encourage users to consume less water and gives them indications on how to do so. This project involved collecting and working with three different datasets with three different temporal scales (monthly billing data, 5-minute water use data, and 5-second water use data). We analyzed monthly billing data to solicit potential participating facilities for the study.
For each participating facility, new smart devices were installed on their existing water meters, including an advanced water meter register and a pulse counting data logger. The newer registers logged and transmitted data to a web-accessible data portal at 5-minute intervals, while the pulse counters recorded water use at 5-second intervals. These devices enabled us to measure the timing and volume of different water uses (e.g., indoor versus outdoor versus industrial processes uses). In this project, we identified different water use events, average water used by each end use (from plumbing fixtures to industrial machinery), variability in end uses (faucets/toilets versus showers), variability in use by the type of user (manufacturing facilities versus assisted living homes), and the impact of the business type on the water use.
DEDICATION

To my

Companionate mother:

Majedah,

Supportive brother: Ma’moon

Caring and invaluable sisters: Noor,

Alaa, and Hoor, and wonderful

extended family

This thesis is dedicated to all of

them.
ACKNOWLEDGMENTS

I would like to express my gratitude and appreciation to my advisor and mentor Dr. Rosenberg for believing in me. Working with Dr. Rosenberg was such an amazing experience. His guidance helped me in all the time of research.

Besides my advisor, I would like to thank my research committee members, Dr. Jeffery Horsburgh, and Dr. Kelly Kopp for their helpful comments and encouragements. I would also like to thank my research group for their endless feedback throughout my degree. My thanks also go to my research sponsor the Utah Water Research Laboratory, for funding my research and providing all the services that made a difference in advancing my thesis.

Nour M. Attaallah
CONTENTS

Page

ABSTRACT ........................................................................................................... ii
PUBLIC ABSTRACT ........................................................................................ iv
DEDICATION ....................................................................................................... vi
ACKNOWLEDGMENTS ....................................................................................... vii
LIST OF TABLES .................................................................................................. x
LIST OF FIGURES ................................................................................................ xi

CHAPTER

1. INTRODUCTION ............................................................................................. 1

2. METHODOLOGY ............................................................................................ 8
   2.1 Monthly Water Use Data ........................................................................... 8
   2.2 Statistical Analysis .................................................................................. 10
      2.2.1 Normality Test .............................................................................. 10
      2.2.2 ANOVA Test ................................................................................. 11
      2.2.3 Ranking ......................................................................................... 13
   2.3 5-Minute and 5-Second Data Collection ................................................... 15
   2.4 Walk Through ......................................................................................... 17
   2.5 Meter Testing .......................................................................................... 18
   2.6 Data Collection Methodology ................................................................... 20
   2.7 Events Disaggregation ............................................................................ 22
   2.8 Results Verification ................................................................................ 26

3. RESULTS ........................................................................................................... 27
   3.1 Temporal Scales ...................................................................................... 27
   3.2 Classification Results .............................................................................. 29
      3.2.1 Irrigation ....................................................................................... 30
      3.2.2 Industrial Use and Humidifiers ....................................................... 33
      3.2.3 Showers ....................................................................................... 33
      3.2.4 Unclassified Events ..................................................................... 35
3.3 Per Capita Water Use........................................................................................................36
3.4 Time of Use Patterns........................................................................................................38

4. DISCUSSION........................................................................................................................39
   4.1 Limitations and Challenges............................................................................................43

5. CONCLUSIONS.....................................................................................................................47
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Water use data quantiles</td>
<td>10</td>
</tr>
<tr>
<td>2.</td>
<td>Business type impact on water use</td>
<td>12</td>
</tr>
<tr>
<td>3.</td>
<td>Different types of end uses in each facility</td>
<td>18</td>
</tr>
<tr>
<td>4.</td>
<td>Minimum resolution of pulse outputs by flow rate and meter size</td>
<td>19</td>
</tr>
<tr>
<td>5.</td>
<td>Landscape irrigation ratio vs. irrigation efficiency</td>
<td>31</td>
</tr>
<tr>
<td>6.</td>
<td>Potential conservation actions and their associated water savings</td>
<td>42</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>CII entity relationship database diagram</td>
<td>9</td>
</tr>
<tr>
<td>2.</td>
<td>(A) Water use distribution of the CII sector without any transformation;</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>(B) Water use distribution of the CII sector after log transformation.</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Water use per user type</td>
<td>13</td>
</tr>
<tr>
<td>4.</td>
<td>Top panel shows the water use by top Logan CII users. The bottom panel</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>shows the pervious area in square feet for the same users.</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Metering System</td>
<td>20</td>
</tr>
<tr>
<td>6.</td>
<td>Data collection window for 5-seond data</td>
<td>21</td>
</tr>
<tr>
<td>7.</td>
<td>Water use collected at different temporal scales for the month of August 2017</td>
<td>28</td>
</tr>
<tr>
<td>8.</td>
<td>A zoomed in view of the 5-sec data showing different end uses.</td>
<td>29</td>
</tr>
<tr>
<td>9.</td>
<td>Disaggregated water use by end use</td>
<td>29</td>
</tr>
<tr>
<td>10.</td>
<td>Figure 10: Distributions of outdoor water use event features:</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>(a) durations, (b) volume, and (c) flow rates)</td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>Comparing manufacturing and assisted living homes showering behavior</td>
<td>34</td>
</tr>
<tr>
<td>12.</td>
<td>Shower times</td>
<td>35</td>
</tr>
<tr>
<td>13.</td>
<td>Comparison of per capita water use for four facilities during the months of</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>December and January and to the Utah public community systems study</td>
<td></td>
</tr>
<tr>
<td>14.</td>
<td>Average hourly water use during (a) Winter and (b) Summer</td>
<td>38</td>
</tr>
<tr>
<td>15.</td>
<td>Stratified sampling</td>
<td>45</td>
</tr>
</tbody>
</table>
CHAPTER 1
INTRODUCTION

Commercial and industrial water users have a significant impact on drinking water demand and exhibit a diurnal pattern that can be completely different from residential users (Blokker et al., (2011)). According to the United States Geological Survey (USGS), about 29% of water is utilized by the non-residential sector. The Pacific Institute Report *Waste Not, Want Not* (Moran (2009)) classified the non-residential sector into three different categories: (1) Commercial: Private facilities providing or distributing a product or service, such as hotels, restaurants, or office buildings, (2) Industrial: Facilities that mostly manufacture or process materials as defined by the North American Industrial Classification System (NAICS), and (3) Institutional: Public facilities dedicated to public service including schools, courthouses, government buildings, and hospitals.

Commercial, Industrial, and Institutional (CII) water use varies from region to region, or even in the same region among different water utilities and from one business to another. Some businesses—industrial in particular—use water as an input in the production line, while others may have end uses similar to residential units (e.g., toilets, faucets). Estimating gallons/employee/day for different CII employment groups has proved to be more challenging (Nourani, M. & Bader, T., (2009)). This is mainly because it is sometimes difficult to obtain information regarding the number of employees working for a business. Even when the number
of employees is tracked, it’s not easy to pin it down accurately due to working
shifts, working hours, and seasonal surges in production. Furthermore, some
businesses’ water use does not correlate very well to the number of employees,
especially businesses that use water as an input to the production process.

Efficient water management for the CII sector requires knowledge of when,
by whom, and how water is being used (e.g., cooling towers, humidity maintainer,
washing machines, batch wash, etc.). Regular metering has the ability to answer the
first two questions (when and by whom) where meters are read monthly by a person
for each customer, and a water bill is generated from this manual reading of the
meter. However, identifying how water is consumed inside a facility requires a
meter that is capable of collecting data with high frequency (5 seconds intervals or
less, for instance). Smart meters can bring this dilemma into real time monitoring of
water use enabling us to identify how water is used inside a facility. Meters that are
capable of collecting data with high frequency can provide a better understanding
of water demand, which is critical to properly evaluate water stress and to quantify
the impact of water withdrawals on the current water supply strategies.

Most high frequency data monitoring studies focused on the residential
sector. Studies in (1) the United States (Aquacraft, (2010)Almeida et al. (2011)) and
(3) Australia (Coates and Bullock, (2008)) proposed different water use
identification approaches for residential users. However, the same data collection
method was used (i.e., water meters with pulsed output and data loggers), and each
project went through the same three stages of (1) data collection, (2) data analysis,
and (3) assessment of the collected information.
Aquacraft (2010) developed a method for disaggregating residential end uses of water using a single flow trace file obtained from the utility owned water meter. Flow traces consist of readings at 10-second intervals down to the nearest .01 gal. Individual events were classified by volume, duration, flow rate and start time. (Almeida et al. (2011) used pattern recognition of the household water consumption through signal analysis to identify the end uses. Almeida tested two different algorithms to identify the best classifier for the data: (1) multilayer perceptron, and (2) support vector machine (SVM), where the first approach showed a better accuracy. Coates and Bullock (Coates and Bullock, (2008)) were able to disaggregate water use into individual end uses through the Trace Wizard software developed by Aquacraft after collecting data at 5-second intervals for two weeks.

DeOreo et al. (2016) disaggregated household water use by fixture for 900 of the 23,749 random selected households in the US. The study collected highly detailed information on water use from 2010 to 2013, which involved recording water flow every 10 seconds for a period of two weeks through utilizing Meter-Master flow recorder installed on a magnetic drive water meter (F. S. Brainard Company). High level flow data were successfully obtained from 762 homes. It was found that toilet flushing is the largest indoor use of water, followed by faucets, showers, clothes washers, leaks, bathtubs, other/miscellaneous, and dishwashers. Moreover, the study compared results to the original 1999 residential end uses of water study (DeOreo et al. (1999)) and found that per capita average water use decreased 15 percent, from 69.3 gal/capita-day in 1999 to 58.6 gal/capita-day in
2016. More water efficient appliances account for the decrease in indoor use between the two studies. Other new investigations in this field (Cominola et al. (2015)) launched the smart H2O Project. The project aimed to take advantage of the smart water network technologies for better management of urban water distribution systems considering both the supply side (i.e., utility) and demand side (i.e., customers). The smart metering system traced when and how customers use water. The main output of the project was to increase the efficiency of water supplier operations.

As for non-residential studies, several have been implemented in different places in the world by disaggregating water consumption by subsector. However, the major studies of commercial and industrial water users have not used smart meters. In the U.S. Army Corps of Engineers’ Institute for Water Resources Municipal and Industrial Needs (IWR-MAIN) model (Dziegielewski & Boland, (1990)), the size and water use of each CII sector was estimated by total employment where water use was estimated as the number of employees times the average per capita water consumption. Statistical data on employment are provided according to the NAICS code. Outside of the census, employment figures can be derived from commercial surveys, which are more thorough and precise because data are collected at the customer level.

The 2008 water use efficiency plan for New Mexico found that restaurants, office buildings, and health care facilities are the largest water users in the CII sector. At the end of the study, detailed end uses of water for CII sector were retrieved (Water Use Efficiency Plan, (2008)). A sub-metering technique was used,
where water meters were employed in each water fixture or process of an industry. The study involved collecting data from 25 commercial and institutional sites.

In another study in Florida, the researchers used parcel-level information for every land parcel in the state (Nourani, M. & Bader, T., (2009)). The Florida Department of Revenue (FDOR) database, in conjunction with Florida County Property Appraisers (FCPA), provided the heated building area for every land parcel in the state along with the land use classification, allowing for subsector specific water use coefficients. Additionally, historic monthly water billing data for 3,127 CII parcels were linked with parcel-level land use features. Water use coefficients normalized by heated building area were developed. Heated area was the best predictor of water use available from the property attributes evaluated and little was gained from the other variables (Morales, M. & Heaney, J., (2010)). Linking parcel-level attributes with parcel-level water use billing data enhanced the ability to estimate CII water use. The customer classifications in these databases allow the user of the Guide to define the level of disaggregation within the CII sector. The sum of the heated area of a sector was the size used to estimate its water use.

At the institutional level, a smart metering technique was used on the campus at Utah State University to quantify potential water savings after installing high efficiency water fixtures in two high-traffic men’s and women’s bathrooms at high temporal frequency (0.25 Hz) (Horsburgh et al, (2017)). Recording water use events at high frequency allowed researchers to: i) monitor water use behavior and identify water fixture malfunctions; ii) understand the variability in water use by
fixtures; iii) differentiate gender behavior in water use.

In the above studies, smart metering has primarily been used in residential settings. Work with commercial and industrial users is challenging due to the heterogeneity of users and end-uses, multiple business or facilities can share the same water meter (e.g., strip malls), different sizes of service lines, potential for multiple service lines, meters, and meter heads (registers) per user, large fluctuations in uses, variable number of people in the facility, continual water use (no chance to isolate appliances or end uses), difficulty to identify the person to contact to solicit participation in the study, and the low water cost compared to other business or industrial inputs.

To address some of these challenges of measuring water use in the commercial and industrial sectors, this research works with three data streams collected at three different temporal scales (monthly billing, 5-minute, and 5-second). We used monthly billing data paired to business licensing and landscape data to select and recruit facilities to monitor water use at higher temporal frequency. We used data collected from smart meters every 5 minutes and every 5 seconds over ~11 months for 6 CII users in Logan City, Utah to characterize time of day water use and water use by different water fixtures and processes. We designed the data collection to answer three research questions: 1) How to quantify water use by fixture and process in commercial and industrial facilities using a non-invasive approach? 2) What is the peak demand and how does demand change with time of the day?, and 3) What are the main similarities and differences between these CII users and residential users? Collected data are shared on Hydroshare
(Atallah, 2018). Data analysis allowed us to check the appliance technical performance of common plumbing fixtures (e.g., showers), and to identify a set of new water use signature patterns of industrial and commercial uses that utilize water in their process (e.g., pressure jets). Research findings can help individual CII study participating facilities and water providers understand current water use and improve water use efficiency.
CHAPTER 2
METHODOLOGY

Study methods work on three water use datasets with monthly, 5-minute, and 5-second temporal scales. Monthly data was analyzed to identify and recruit larger water use facilities to monitor at higher temporal frequency.

2.1 Monthly Water Use Data

Logan City shared monthly water use billing and related business licensing and storm water data for all 472 commercial and industrial customers within the city for a two-year period (2014-2016). The Water Consumption data included monthly water use billing data collected between October 2014 to June 2016 for all 472 different CII customers within the City of Logan, Business licensing data included descriptive metadata maintained by Logan City that identified for each CII user the business mailing address, business class, North American Industry Classification System (NAICS) codes, license number, and physical address, and 3.) Storm Water: included parcel size, landscaped areas, and land cover.

Using the database designer in MySQL Workbench, we designed a blank schema for the database and then we used the import wizard in MySQL Workbench to import data where we integrated the three datasets into the designed relational database schema (Figure 1).
The three datasets were linked based on the physical address attribute, which was the common attribute among the three datasets. After linking, the process of sorting and categorizing the data was performed in order to have a highly-normalized database where tables are organized with relations to reduce data redundancy and improve data integrity. In that process, the water consumption dataset was divided into two sets of tables within the database, one set for the water use data values and another set to store information about the meters associated with each business.

Figure 1: CII entity relationship database diagram
2.2 Statistical Analysis

We applied Shapiro-Wilk normality and ANOVA tests to characterize the frequency distribution of the monthly billing data and identify correlations between the water use data and the type of the business. RStudio was used for the statistical analysis (Atallah, 2018).

2.2.1 Normality Test

Since many parametric statistical tests rely upon the assumption of normality, we used the Shapiro-Wilk normality test to verify/refute the null hypothesis that the CII data is normally distributed.

The frequency distribution of water use data showed that the majority of users consumed less than 2,000 gal/day (Figure 2-a). This was also verified in Table 1 that where 75% of water use records were less than 2,000 gal/day causing a positive skewness of the water use records.

Table 1: Water use data quantiles

<table>
<thead>
<tr>
<th>Quantile</th>
<th>0%</th>
<th>25%</th>
<th>50%</th>
<th>75%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Use (gal/day)</td>
<td>3</td>
<td>182</td>
<td>646</td>
<td>1962</td>
<td>105229</td>
</tr>
</tbody>
</table>

The P-value for the Shapiro-Wilk test was 2.2e-16, which is less than 0.05 and indicates that the water use data are not normally distributed. This skewed distribution of these CII water use records follows similar skewed findings in several residential water use studies (Abdallah et al. (2012); Suero et al. (2012); Rosenberg et al. (2008)).
Since the distribution of the measurement variable (water use data) does not fit a normal distribution, data transformation is needed to better interpret patterns in the data and meet the assumptions of inferential statistics. A Log transformation was used, the Shaprio-Wilk test was again performed on the transformed data, and the test value was 0.5, which is high enough (P-value > 0.05) to accept the hypothesis of normality of the log-transformed data (Figure 2).

![Water use distribution of the entire CII sector in Logan (472 businesses). Panel (a) shows the data without any transformation. Panel (b) shows the same data after log transformation](image)

Figure 2: Water use distribution of the entire CII sector in Logan (472 businesses). Panel (a) shows the data without any transformation. Panel (b) shows the same data after log transformation

2.2.2 AVOVA Test

We inspected whether there is a correlation between the CII water use and the type of the business. As mentioned earlier, the type of a business can be identified using NAICS codes. NAICS codes classify businesses based on the particular product or service they supply and place them into the appropriate group. There are 20 different groups (Manufacturing, Nursing homes,
Construction, Education, etc), and each business type can fit under only one group. Since business type is categorical, the correlation coefficient is calculated as the P value of ANOVA test.

In the developed generalized linear model, Manufacturing and Health Care and Social Assistance facilities had p-values less than 0.05 and suggest that water use is correlated to those two facility types. For other CII categories like information, p-values were greater than 0.05 and suggest facility type and water use are not correlated (Table 3).

Table 2: Business type impact on water use

<table>
<thead>
<tr>
<th>Business Type</th>
<th>Significance (P-Value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing</td>
<td>0.03</td>
</tr>
<tr>
<td>Health Care and Social Assistance</td>
<td>0.04</td>
</tr>
<tr>
<td>Retail Trade</td>
<td>0.11</td>
</tr>
<tr>
<td>Wholesale Trade</td>
<td>0.15</td>
</tr>
<tr>
<td>Real Estate Rental and Leasing</td>
<td>0.17</td>
</tr>
<tr>
<td>Professional Scientific and Technical Services</td>
<td>0.24</td>
</tr>
<tr>
<td>Educational Services</td>
<td>0.25</td>
</tr>
<tr>
<td>Finance and Insurance</td>
<td>0.26</td>
</tr>
<tr>
<td>Construction</td>
<td>0.29</td>
</tr>
<tr>
<td>Other Services (except Public Administration)</td>
<td>0.32</td>
</tr>
<tr>
<td>Administrative and Support and Waste Management and Remediation Services</td>
<td>0.41</td>
</tr>
<tr>
<td>Arts Entertainment and Recreation</td>
<td>0.47</td>
</tr>
<tr>
<td>Public Administration</td>
<td>0.62</td>
</tr>
<tr>
<td>Transportation and Warehousing</td>
<td>0.66</td>
</tr>
<tr>
<td>Mining</td>
<td>0.69</td>
</tr>
<tr>
<td>Agriculture Forestry Fishing and Hunting</td>
<td>0.72</td>
</tr>
<tr>
<td>Information</td>
<td>0.99</td>
</tr>
</tbody>
</table>
2.2.3. Ranking

Using the monthly billing data, we also estimated and ranked the average daily water use for each business as the total water use for a business over the number of bill period days. Rankings indicated that the top CII categorized water users in the City of Logan were manufacturing and health care facilities (Figure 3). Therefore, we focused further high-frequency monitoring on those subsectors as they have the biggest impact on the CII water use.

<table>
<thead>
<tr>
<th>NAICS (Category)</th>
<th>Participant’s Type</th>
<th>Non-Categorized Users</th>
<th>Other User Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Categorized</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Health Care</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accommodation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retail Trade</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation and Warehousing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Services</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Public Administration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Professional and Technical Services</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Finance and Insurance</td>
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<tr>
<td>Arts and Recreation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wholesale Trade</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Information</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Educational Services</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agriculture and Hunting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real Estate Rental</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Administrative and Support</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mining</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3: Water use per user type

From the 472 CII Logan customers we contacted managers from 15 of the top 22 water use facilities and solicited their participation to monitor their water use at high frequency (every 5 seconds). We did not hear back from some
managers, others had concerns regarding participation in the study, and a few managers declined to participate in the study. 6 facilities agreed to participate in the high-frequency monitoring (Figure 4; 40% response rate). Four manufacturing facilities produce circuit boards, metals, or printed materials (Manufacturing #1-4) and have unique features, including 24/7 working hours, 4 different water meters serving a single facility, and more than 200,000 ft² of irrigated turf grass. The other two facilities (Assisted Care #5-6) are assisted living facilities with more than 70 residents and over 300 different fixtures in each facility (e.g., faucets, toilets, urinals, sprayers, showers, storage tanks, and commercial cloth washers).

A representative for each facility signed an informational letter that described the study and data sharing provisions. These provisions included that we could place an anonymized version of high-frequency data we collected within a data repository for permanent publication and potential reuse (Atallah, (2018)). A blank copy of the information letter is available at (Atallah, (2018)). The USU Institutional Review Board ruled that this study and methods fell outside their purview since study participants were businesses rather than individual human subjects. To respect the anonymity of facilities, from here on out we will refer to different facilities by an ID (Manufacturer 1, Manufacturer 2, etc.).

Monthly water use data showed that all selected participating facilities had seasonal variations in water use. Also, together the six selected facilities
used 15% of total water delivered to CII sector between 2014 and 2016.

Figure 4: Top panel shows the water use by top Logan CII users. The bottom panel shows the pervious area in square feet for the same users.

2.3. 5-Minute and 5-Second Data Collection

For each participating facility, Logan City staff replaced the preexisting Neptune E-Coder registers atop the existing commercial compound or true-flow Neptune analogue water meters 1.5 to 4” in size with new Innov8 VN register(s)
that logged water use data at 5-minute intervals and transmitted data once per day via a cellular data network to a password protected website (www.waterscope.us). Previously, the E-Coder registers recorded water use at ~monthly intervals via radio-read from a nearby car. Innov8 VN 5-minute data were transmitted to the WaterScope website for a period of 13 months from July 2017 till September 2018. 12 new registers were installed on the 10 meters serving the 6 facilities. The discrepancy between the number of registers and meters was because two participating facilities had 4” compound meters that required two registers (to measure low and high flows).

Compound meters consist of a combination of an AWWA Class II turbine meter for measuring high rates (> 3GPM) of flow and a nutating disc type positive displacement meter for measuring low rates (< 0.5 GPM). The two meters are enclosed in a single main case. Any value between 0.5 and 3 GPM can be measured on either head. An automatic valve directs flows through the disc meter at low flow rates and through the turbine meter at high flow rates. At high flow rates, the automatic valve also serves to restrict the flow through the disc meter to minimize wear (Neptune, 2016). The 1.5”, 2”, and 4” service lines suppling the facilities were larger than the ¾” or 1” lines that typically supply residential properties.

The Metron Innov8 VN registers also came with a 2-wire pulse output cables that we attached to MadgeTech 101A pulse counters. The register fired a pulse every time the register recorded a specified volume of water passed through the meter (further details in next section). We used the pulse wire and counter to
read and record the number of pulse signals every five seconds. To protect the pulse counters from moisture damage, we placed the pulse counters inside weather-proof enclosures that we then zip-tied to the underside of the manhole that provided access to the water meter and meter pit.

The 5-second data were collected for a period of 11 months from August 2017 till June 2018. We conducted monthly site visits to retrieve the data logs stored in the internal memory of the data loggers.

2.4 Walk Through

For each participating facility, we conducted a walk-through of the property with an employee.

The purpose of the walk-through was to identify technology, demographic, and behavioral factors that affect water use at each facility, such as size of the facility (number of employees/residents and landscape area), different types of water uses inside the facility (Table 4), irrigation behavior, working routines, and questions facility staff had about water use and conservation that the study could help answer.
Table 3: Different types of end uses in each facility

<table>
<thead>
<tr>
<th>End Use</th>
<th>Business/ Number of fixtures</th>
<th>Manufacturing 1</th>
<th>Manufacturing 2</th>
<th>Manufacturing 3</th>
<th>Manufacturing 4</th>
<th>Assisted care 1</th>
<th>Assisted care 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batch wash</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cloth washer</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Dishwasher</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Faucet</td>
<td></td>
<td>18</td>
<td>13</td>
<td>7</td>
<td>8</td>
<td>84</td>
<td>133</td>
</tr>
<tr>
<td>Humidity Maintainer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5 pipes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ice machine</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Inland wash</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrigation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressure wash</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rinse</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shower</td>
<td></td>
<td>4</td>
<td></td>
<td></td>
<td>3</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>Sprayer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>Storage tank</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toilet</td>
<td></td>
<td>14</td>
<td>13</td>
<td>3</td>
<td>16</td>
<td>75</td>
<td>62</td>
</tr>
<tr>
<td>Urinal</td>
<td></td>
<td>4</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.5 Meter Testing

To check the compatibility of the meter, register, and pulse counter components when assembled together, we tested the metering components at the Utah Water Research Laboratory in May 2016 using different pipe sizes, meter sizes, and variable flow rates (Figure 5). We also used the tests to determine what pulse rate to use on the pulse counter. The register’s sensor transmits the actual turns of a magnet inside the meter to a microcontroller, which displays the magnitude of water use on the register’s display based on the settings used. When the flow rate is too high, it was suspected that the sensor might get overwhelmed by the number of rotations of the magnet and underreport the actual volume of water flowing through the pipe. Based on the billing data records of the
participating facilities, historical flow rates values varied from 20-70 gal/min. In the test we encountered flow rates up to 100 gal/min and we recorded the finest resolution the datalogger could accurately capture each flow rate.

<table>
<thead>
<tr>
<th>Flow Rate (GPM)</th>
<th>Meter Size (inch)</th>
<th>1&quot;</th>
<th>1.5&quot;</th>
<th>2&quot;</th>
<th>4&quot; - Disc</th>
<th>4&quot; - Turbine</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.5</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>0.5-25</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>N/A</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>25-50</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>N/A</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>50-100</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>N/A</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>100 or more</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>N/A</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

Test results showed that at flowrates below 25 gallons per minute, the pulse counters could record flow volumes as low as 0.1 gallons per pulse. For flow rates above 25 gallons per minute, we discovered that a 0.1 gal per pulse setting massively underestimated the flow rate through the meter. Because of this limitation, and since we did not expect flow rates for participating facilities to exceed 70 gal/min, we used a resolution of one gallon per pulse for the study.
2.6 Data Collection Methodology

5-minute data collected on the VN registers were accessed and retrieved from the WaterScope website. The collection window for the 5-minute data covered thirteen uninterrupted months from July 2017 till the end of August 2018. Higher frequency (5-second) data were collected over eleven months from August 2017 to June 2018 (Figure 6).
The high frequency data were collected on-site and stored in the internal memory of the pulse counters. At 5-second frequency, the storage capacity was 31 days. When the memory filled, the pulse counter stopped recording. For data collection, monthly site visits were conducted to retrieve the data logs. Due to the schedule of City staff who provided access to manholes and inclement weather conditions during the winter, it was difficult to maintain regular monthly visits to each facility.

Data were later exported from the MadgeTech software to Excel Workbook (xlsx) format. As the dataloggers produced counts of pulses by each meter head every five seconds along with the respective timestamp, we calculated volume of water in gallons by multiplying the count of pulses by the volume of water per pulse (one gallon per pulse in our case). Finally, we designed and developed a local database in MySQL to hold the high frequency records stored in Excel files. The designed database has four different tables: 1.) Participant: personal information of the participating facilities like the name of
the customer, and the address, 2.) Meter: has attributes related to the meters connected to different participating facilities like the size, and the type of the meter, 3.) Pulse Counter: has attributes related to the pulse counters like the serial number of each device, and its status, 4.) WaterUse: the data value table that holds the high frequency records. Foreign keys were used to connect the four tables. The data value table has more than 25 million records of water use measured at 5-second intervals.

2.7 Events Disaggregation

It was difficult to collect data that characterized each individual fixture or train and test end use disaggregation algorithms for the CII users because there were a large number of different water use fixtures inside each facility, different water uses than in residential homes, and measurements were made on the bulk flow through one or more meters serving each facility. Instead, data analysis was performed to identify and quantify each group of fixtures that we expected to have similar signatures. As a study that focuses on non-residential users, the categories of water end use events used for this study were: 1) Industrial, 2) Outdoor, 3) Indoor shower, 4) Indoor faucet/toilet, 5) Network test, and 6) Humidity maintainer.

A raw event was identified as the beginning and end of a subset of consecutive non-zero values $R = (r_1, \ldots, r_n)$ from the smart meter time series $T$. For each unclassified event, we identified the event volume, start time, end time, duration, and peak flow.
To classify raw events, we applied clustering analysis where events with the same features (time of use, volume, and duration) were compiled together and then assigned to a common category.

Outdoor events were identified by time of use (most occurred after midnight and in the early morning), volumes of at least 1000 gal/event, and durations of at least 20 minutes. We investigated the ratio of applied water to landscape water need for two businesses for which we monitored water use during the irrigation season. This ratio was the water volume applied to the landscape divided by the water need (Kratsch (2011)). Water needed by the landscape was calculated as Gallons of Water per day = \((ETo \times PF \times SF \times 0.62)\) (Climate Center, 2018), where \(ETo\) = Reference evapotranspiration (inches per day; values were retrieved from Utah Climate Center Website); \(PF\) = Plant factor, fraction of \(ETo\) needed by plant (unitless; turf grass used = 1.0); \(SF\) = area to be irrigated (square feet retrieved from the Cache County parcel and zoning interactive website (www.cachecounty.org). And 0.62 is a conversion factor to report the output in imperial units (gallons). Based on LIR, irrigation efficiency can be inferred. An irrigation system would be considered efficient if the calculated LIR is less than 1. If LIR is more than 3, water is applied excessively in irrigation. Acceptable irrigation efficiencies are expected to have LIR value between 1 and 3.

Industrial events were identified by volumes of at least 170 gal and durations of at least 12 minutes. Shower events were defined by volumes, durations, and lag times between two consecutive pulses, where consecutive
pulse lag time varied between 10 to 45 seconds. Humidity maintainer events were defined by the day of use, and the flow rate. Humidification systems force moisture into the facility’s indoor air in a form of mist. Humidity maintainer events occurred on days where relative humidity values were less than 35%. The flow rate used in each event of humidification varied from 30 to 60 gal/event.

We were also able to capture network test events. The test was performed by installing the tested meter on one of the network pipelines and running water through the pipe for at least one hour. Network test events had volumes of more than 1000 gal and flow rates about 30 gal/min.

The end use disaggregation algorithm outputs a .csv file with the classified events. The attributes of the generated csv file are the volume (gal), duration (minutes), flow rate (gal/minute), start time, and end time. The algorithm was coded in Visual Studio (C#), and is available at (Atallah, 2018).

The limitations of the event disaggregation algorithm include difficulty in classifying some events with multiple sub-events (e.g., some industrial processes, industrial clothes washers and dishwashers), and simultaneous flows at multiple fixtures (overlapped events from fixtures of different types). Nevertheless, these unclassified events represented only a small portion (less than 10%) of total events. We were able to identify overlapped events produced from the same fixture type (e.g., two concurrent showers). The new signature would be the signature of a single certain fixture multiplied by the number of fixtures running at the same time.
The analysis was divided into two components to answer the three major research questions listed in Section 1. The first component comprised the identification of the average water use from each water use category per business. Average water use per business for a category was calculated as the total volume of water used by fixtures of each category over the monitoring period for each business. The average water use per category estimates the similarities and differences of facilities with comparable fixtures.

The second component of our analysis consisted of calculating a CII per capita water use and comparing that use to the standard residential per capita water use of the City of Logan. Our business contacts provided daily patient census (assisted care facilities) and number of employees (manufacturing facilities) for the months of December 2017 and January 2018. CII per capita water use was calculated as the total volume of indoor water use divided by the number of people working or residing within the facility. Public community systems in Utah (Utah, DWRe (2005)) estimated that residential sector uses 182 gal/capita-day, commercial sector uses 17 gal/capita-day, institutional sector uses 30 gal/capita-day, and industrial sector uses 11 gal/capita-day.

The daily use of all these categories amounts to 260 gal/capita-day. DWRe quantified indoor and outdoor residential water use from the 2005 Statewide Water Use Public Community Systems study (Utah, DWRe (2005)). Currently, about 65% of Utah’s residential water is used outdoors and 35% indoors averaging an indoor residential water use of 62 gal/capita-day. We anticipated that per capita water use would provide a good criteria in comparing
2.8 Results Validation

We verified our results by meeting with one or more representatives from each participating facility. In the meeting, we presented the findings that described times of water use, number of events, volume of water used, water use patterns, and duration of events. With the help of the facility representative, we determined whether the results matched the expected water use behavior of the business. Where they differed, we used information we gained while meeting with representatives to identify and better classify some unclassified events. We also got more details of the timing of use of some events. For example, manufacturing facility representatives confirmed the timings of shower events to be just before working hours or at the end of the day while some industrial process events were more likely to occur at night or at a certain season during the year. Assisted care facility staff confirmed the number and timing of classified shower events from shower logs the facilities maintained.
CHAPTER 3
RESULTS

3.1 Temporal scales

Fig. 7 shows the data collected at monthly, 5-minute, and 5-second temporal scales for August 2017. Bringing the three resolutions of data together (months, minutes, and seconds) over the same time period enabled us to define the level of end-use activity each scale can expose.

Panel a shows an example of water use from monthly billing data, nothing can be interpreted from the plot more than the total monthly water use and the average daily water use. Panel b shows an example of water use data collected at five-minute intervals, the plot accentuates the daily water use variation that the monthly data overlooked it. Panel c shows an example of water use data collected at five-second intervals, which revealed more information on the water use behavior of the participating facilities by identifying the potential water use for different end uses.

A zoomed in view of the 5-sec data for a small period of time shown as the red rectangle in Figure 7 shows temporal characteristics of the water use (Figure 8).
Figure 7: Water use collected at monthly (a), five-minute (b), and five-second (c) temporal scales for August 2017.
3.2 Classification Results

Figure 8: A zoomed in view of the 5-sec data showing different end uses.

Figure 9: Disaggregated water use by end use and facility for August 2017- June 2018.
Results in Fig. 9 show that all businesses have large irrigation water use while the largest number of events are for faucets and toilets. Industrial use events, network tests, and humidity maintenance events also use large water volumes. Below, we further describe classification results for each end use.

3.2.1 Irrigation

In the CII facilities that we studied, outdoor use events varied from 1,000 to 60,000 gal/event. We identified the LIR for each facility ranged between 1.44 and 5 (Table 7).

These ratios indicate facilities used at least one and half times more water than what they actually needed for their outdoor usage. Assisted care facility #2 had an outdoor water usage of five times more than what they actually needed in the month of June.

Results also show some outdoor water use activity for manufacturing 3 facility in October even though the irrigation system is recommended to be turned off by the end of September because the Utah growing season ends by October.
<table>
<thead>
<tr>
<th>Business ID</th>
<th>Month</th>
<th>Landscape Water Used (G/day)</th>
<th>Landscape Water Needed (G/day)</th>
<th>Landscape Irrigation Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing 1</td>
<td>August</td>
<td>13327</td>
<td>5250</td>
<td>2.54</td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>7498</td>
<td>3320</td>
<td>2.26</td>
</tr>
<tr>
<td></td>
<td>May</td>
<td>6655</td>
<td>3759</td>
<td>1.77</td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>8650</td>
<td>5063</td>
<td>1.71</td>
</tr>
<tr>
<td>Manufacturing 2</td>
<td>May</td>
<td>9729</td>
<td>4444</td>
<td>2.19</td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>14345</td>
<td>5987</td>
<td>2.40</td>
</tr>
<tr>
<td>Manufacturing 3</td>
<td>August</td>
<td>43268</td>
<td>30008</td>
<td>1.44</td>
</tr>
<tr>
<td></td>
<td>September</td>
<td>43707</td>
<td>18972</td>
<td>2.30</td>
</tr>
<tr>
<td></td>
<td>October</td>
<td>13559</td>
<td>16800</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>May</td>
<td>30036</td>
<td>21480</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>45008</td>
<td>28933</td>
<td>1.6</td>
</tr>
<tr>
<td>Manufacturing 4</td>
<td>May</td>
<td>8476</td>
<td>3743</td>
<td>2.26</td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>18242</td>
<td>5041</td>
<td>3.62</td>
</tr>
<tr>
<td>Assisted Care 1</td>
<td>May</td>
<td>6101</td>
<td>2807</td>
<td>2.17</td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>8331</td>
<td>3781</td>
<td>2.20</td>
</tr>
<tr>
<td>Assisted Care 2</td>
<td>May</td>
<td>1081</td>
<td>515</td>
<td>2.10</td>
</tr>
<tr>
<td></td>
<td>June</td>
<td>3389</td>
<td>671</td>
<td>5.05</td>
</tr>
</tbody>
</table>

This high use is mainly because facilities irrigate landscaping for long durations which exceeded 20 hours for some events at high flow rates (Figure 10). Proper management of sprinkler irrigation systems can greatly boost the irrigation efficiencies and reduce the total water use. This can be maintained by matching the application rate and duration to the actual water needs of the landscape.
Figure 10: Distributions of outdoor water use event features: (a) durations, (b) volume, and (c) flow rates

Panel (a) in Figure 10 shows that at least 75% of irrigation events lasted less than 120 mins. Manufacturing 3 had a couple of irrigation events that lasted more than 1000 mins. Panel (b) shows that irrigation events for all of the businesses except for manufacturing 3 had a median of 15,000 gal/event. Manufacturing 3 facility had volumes that exceeded 20,000 gallons/event. The long durations and the huge volumes of water associated with it for Manufacturing 3 comes from the fact that the facility has more than 200,000 ft² of irrigated area. Flow rate values for all of the businesses varied between 20
3.2.2 Industrial use and Humidifiers

Industrial water use for Manufacturing facilities #2 and 4 varied from 300 to 400 gal/event. The industrial usage of water inside those facilities was mainly utilized by pressure wash process. In contrast, humidity maintainer values varied for the two manufacturing facilities that had them based on the size of each facility, the humidification method used, and the capacity of the steam humidification pipelines inside each facility. Manufacturing facility 1, used manual technique to maintain a certain level of humidity inside the facility. On the other hand, Manufacturing 3 used an automated steam humidification system that turns on when humidity levels are less than 30%.

3.2.3 Showers

The average water use for showers was around 25 gal/event. Identifying shower events offered an understanding of work-related showering habits of people working at manufacturing facilities. It also provided a comparison between showering habits for residents of long-term assisted care facilities and residential users.

5,976 Shower events were compiled from one manufacturing facility over a period of six months (131 events) and two assisted living homes over a four-month period (5,845). For the manufacturing facility, 75% of shower events lasted less than 8 minutes while for the assisted care facilities, 75% of
their shower events lasted less than 11 minutes with many outliers with durations more than 15 minutes (Figure 11). The longest shower duration was 24 minutes and was recorded by one of the assisted care homes. According to the data, a six-minute shower used around 15 gal of water while the eleven-minute shower used approximately 33 gal of water (Figure 11). According to REUWS (2016), an average shower in the U.S. uses approximately 17.8 gal.

50% of the showers inside the manufacturing facility had flow rates that varied from 2.6 gal/min to 3.7 gal/min which exceeds the maximum flow rate of 2.5 gal/min set by the US energy policy act. On the other hand, 50% of shower events of the assisted living facilities had flowrates that varied from 2 gal/min to 3gal/min which comply with the standards. Few shower events inside the assisted care homes had flow rate values more than 5.5 gal/min (Figure 11).

![Figure 11: Comparing manufacturing and assisted living homes showering behavior](image)
For the assisted living facilities, shower events were distributed throughout the day whereas manufacturing facility shower events were either at the beginning (before 8:00 AM) or at the end of the day (after 3:00 PM) (Figure 12).

Figure 12: Shower times.

3.2.4 Unclassified Events

Remaining events were unclassified, had flow rates, volumes, and durations that varied between (12-16) gal/min, (7-29) gal, and (0.5-2) min respectively. These unclassified events could include industrial cloth washers and dishwashers (e.g., in the assisted care facilities) or overlapped events from the same or difficult fixtures occurring at the same time. The fraction of events we were not able to classify was ~ 10% of total events. They amounted to
approximately 120,000 gal across all facilities and all time.

3.3 Per Capita Water Use

We estimated indoor per capita water use in December and January for the two assisted care facilities and two manufacturing facilities to compare water use among the facilities and to residential users (Figure 13).

Figure 13: Comparison of per capita water use for four facilities during the months of December and January and to the Utah public community systems study.

GPCD estimates from the assisted living facilities can be directly compared to Utah’s indoor residential GPCD since both of them share many of the same water use behavior characteristics. GPCD estimated from the assisted
living facilities varied from 48, which is 14 GPCD less than Utah’s overall GPCD, to 105, which more than doubles Utah’s overall GCPD (Figure 13). For the manufacturing facilities, GPCD values varied from zero to 40 gal/capita-day averaging 8 gal/capita-day for manufacturing 1 and 15 gal/capita-day for manufacturing 2 which complies with Utah’s industrial GPCD water use of 11 gal/capita-day. Zero values in industrial facilities reflected weekend days where there is no water use. The overall GPCD values for the assisted living homes were much higher than those of the manufacturing facilities we compared. This generally makes sense because assisted living homes have residents and staff who consume water all day long, whereas manufacturing businesses have limited working hours.

GPCD represents workers water use outside their homes. Thus, GPCD measurements are very contextual which is noticed in figure 13 and a person’s total indoor water use per day could be up to 35% higher than prior published indoor GPCD values. Although the GPCD method is simple, it has some limitations. The method focuses on average water use rates in each category of use. This simplification ignores trends, variability among users or by a single user, changes in water use due to conservation, user type, or working hours. The accuracy of the method depends both on the water use coefficient and on the underlying activity assumed to drive water use.
3.4 Time of Use Patterns

Using the 5-minute data, we investigated the temporal water usage patterns for the six participating businesses by quantifying the average hourly water use over the entire period of data collection (Figure 14).

Figure 14: Average hourly water use during (a) Winter and (b) Summer.

In the top panel of figure 4, manufacturing facilities showed no variation in winter water use throughout different hours of the day whereas assisted living homes had two peaks in their hourly water use. One peak was in the early morning and another in the evening and were driven by shower events. The bottom panel figure 4 shows all businesses had their summer water peak demand from midnight to early morning which was up to three times the daytime use and driven by outdoor water use activities.
CHAPTER 4
DISCUSSION

In our study, we monitored water use for 6 different non-residential users in Logan, Utah. For each user, data were collected at monthly, 5-minute, and 5-second time intervals for, respectively, two years, 11 months, and four to 11 months. This data included more than 200,000 separate water use events that were extracted from more than 25 million individual water use records. This monitoring period is much longer than prior studies of residential users that collected high-frequency (<10 sec) water use data for two-weeks to 1 month (Aquacraft, 2010; DeOreo et al., 2016). This period of high-frequency monitoring is also longer than any prior study of non-residential water use.

We found that outdoor water use during the irrigation season accounted for more than 60% of total annual water use. Landscape irrigation ratios varied from 0.8-5.5. The poor irrigation behavior caused a significant water loss which accounted for more than 40% of total water delivered to the business. The outdoor water use estimates positively related to the lot size landscaped area. Facilities with large irrigated areas used water for long times at high flow rates compared to other users with smaller irrigated areas.

The large fractions of outdoor water use by the commercial and industrial facilities we studied are similar to large outdoor use by residential users. However, the facilities we studied have much larger landscapes than residential users, so they
use much larger volumes of water.

Monitoring water use at 5 second frequency enabled us to quantify several end uses of water for non-residential users and the efficiency of some of those end uses. Water use per toilet flush varied from 1.4-1.9 gal/flush with an overall average of 1.6 gal/flush which is 38% less than the 2.2 gal/event toilet events recorded for residential users in the REUWS study. Toilet flush rates for the businesses we studied were similar to the EPA toilet flush standard of 1.6 gal/flush. Shower events in the one manufacturing facility we studied with showers had an average flow rate of 3.5 gal/min and exceeded the 2.5 gal/min Mandated US Energy Policy flow rate by 1 gal. In contrast, shower flow rates in the two assisted living homes we studied complied with mandated flow rate but exceeded the 2.1 gal/min flow rate recorded for residential users in the REUWS study.

The variation in water used by humidity maintenance systems in Manufacturing 1 and Manufacturing 3 came from the technique each business used to maintain a humidity level. For Manufacturing 1, manual technique was used to maintain a certain level of humidity inside the facility. Manufacturing 3 had a steam humidification pipeline system that automatically turns on when humidity levels are less than 30%.

Industrial water use varied from 300-400 gal/event with an average flow rate of 15 gal/min. Industrial humidity maintenance systems are not typically present in residences and to our knowledge this is the first estimate of water use for these systems. However, water use from humidity maintainers can be compared to the swamp coolers products used for cooling in residential units. The water use
obtained from the swamp’s manufacturer manual varies from 5 gal up to 50 gal for large units which is (3-5) times smaller than the ones logged at manufacturing facilities. Having larger water use for manufacturing facilities is reasonable since they are expected to have larger indoor floor areas bigger than residences.

The peak hour demand for each of the selected participating facilities ranged from 30 gal/hr to 2,100 gal/hr. Facilities exhibited different diurnal patterns. Peak periods for the participating facilities were in the dawn with slight variation in water use during other times of the day. The peak demand is driven by either irrigation water use or industrial activity use. Daytime/nighttime and indoor/outdoor patterns of water use for the commercial and industrial facilities we studied are similar to residential patterns. However, commercial and industrial facilities use much larger volumes than residential users.

The findings above suggest that several of the indoor and outdoor water conservation actions typically recommended for residential users can also be suggested for these commercial and industrial users but may have larger effects (Table 9). WaterSence efficient toilets, showers, and faucets use 0.8 GPF, 1.25 GPM, and 1.2 GPM, respectively, which is ~ 20% more efficient than the current regular standards.

Water savings were calculated as the water use difference of the current end uses and the WaterSence efficient ones multiplied by the total number of events of each end use. Landscape irrigation savings were calculated as the difference between the water used in irrigation and the water actually needed for irrigation.
Table 6: Potential conservation actions and their associated water savings (gallons/11 months).

<table>
<thead>
<tr>
<th>Potential Conservation Action/ Business</th>
<th>Reduce flow rates and duration of sprinkler events</th>
<th>Retrofit toilets, showers, and faucets to WaterSence efficiency standards</th>
<th>Switch to automatic humidification technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing 1</td>
<td>18738</td>
<td>26078</td>
<td>175</td>
</tr>
<tr>
<td>Manufacturing 2</td>
<td>13643</td>
<td>295013</td>
<td>-</td>
</tr>
<tr>
<td>Manufacturing 3</td>
<td>76158</td>
<td>66790</td>
<td>-</td>
</tr>
<tr>
<td>Manufacturing 4</td>
<td>17934</td>
<td>417635</td>
<td>-</td>
</tr>
<tr>
<td>Assisted care 1</td>
<td>7844</td>
<td>356114</td>
<td>-</td>
</tr>
<tr>
<td>Assisted care 2</td>
<td>3284</td>
<td>135251</td>
<td>-</td>
</tr>
<tr>
<td>Savings (gal)</td>
<td>137628</td>
<td>1305881</td>
<td>175</td>
</tr>
</tbody>
</table>

Table 9 shows that a proper management of sprinkler irrigation systems of the participating user could save 137628 gal of water per year. Retrofitting some of the fixtures could also lead to potential savings of another one million gal of water. Despite the fact that irrigation events use larger amount of water per event, they only occur during the irrigation season (~ 6 months) which means a smaller year-round consumption than domestic fixtures. Automating the humidification system for Manufacturing 1 could save 177 gal/event.

Identifying water usage patterns is essential for the water managers to effectively understand how their non-residential customers utilize the water throughout the day. The GPCD estimates and the hourly water use trends showed that an assisted care facility will have a water use behavior similar to the residential one with an average indoor GPCD of 65 gal/capita-day. The water demand peaks of the assisted care facilities were in the morning and in the evening hours matching the two peaks hours of the residential users. The proposed conservation scenario showed that adopting some conservation actions could potentially yield total savings of 1443509 gal over the eleven-month period for which we collected...
data. This is about 30% of the total water currently used. Exploring more scenarios and deciding on the best in terms of water savings and convenience to the end users can help guide future conservation efforts by water managers nationwide.

4.1 Limitations and Challenges

Compatibility between the metering components

We had to monitor water use at one gallon per pulse instead of 0.1 gallon per pulse. This monitoring frequency prevented us from collecting data with higher volumetric resolution to differentiate faucet and toilet flush events. The 1 gallon per pulse rate also changed the expected signature of some end-uses and/or provided multiple signatures for the same end use like the faucet/toilet and the shower events.

Irregular data collection

Due to the tight schedule the city had, it was difficult to maintain regular site visits to collect 5-second water use data. The irregular data collection resulted in gaps within the 11-month data collection window. Although we placed the pulse counters inside weather-proof enclosures, moisture still infiltrated into some pulse counters causing loss of several months’ worth of data for some customers and meters.
Classification errors

It was difficult to collect, train, and test data from each fixture and we were not able to identify some events.

In CII facilities, there is often multiple water end uses operating at the same time, the obtained time series water data is the aggregation of water use from concurrent end uses. Overlapped events from the same end use type were classified where the classification output was the signature of the end use multiplied by the number of same end use type running at the same time. Overlapped events from different end uses smaller water volumes events were counted as part of larger ones. For example, a toilet flush during an irrigation event might not get classified separately because the flow rate of the irrigation event was so much higher than the flow rate of the toilet event. The fraction of events we were not able to classify was less than 5% of total events. They amounted to approximately 120,000 gal across all participating facilities and all time.

Stratified sampling

We collected high-resolution water use data for six commercial and industrial facilities in Logan City with large water use. A significant challenge lies in scaling this information from the sample of 6 facilities to a larger number of facilities within a municipality. Yet, this scaling would provide valuable information for water managers interested to characterize commercial and industrial water use at the city level and/or encourage conservation. Top panel of Figure 15 uses pervious area and average daily water use data provided by Logan City to
compare existing water use and expected water savings by study participating facilities (red circles and orange stars) to existing water use by the 466 remaining businesses (blue crosses). The bottom one (b) uses NAICS classification and average daily water use data to compare existing water use and expected water savings by study participating facilities to existing water use by the 466 remaining businesses.

Figure 15: Stratified sampling

Here, pervious area is a surrogate for landscaped area and outdoor water use. Figure 15 shows that participating facilities with larger water use are expected
to save the most water if they adopt conservation actions. Also, that large water use and savings by commercial and industrial facilities can occur across a range of pervious areas. Third, at least 100 commercial and industrial facilities in Logan, Utah have daily water use greater than 2,500 gal/day and similar to study participating facilities; these facilities may also be able to save large volumes of water if they adopt conservation actions. And finally, the 77 facilities with similar NAICS code (44 Manufacturing facilities and 33 assisted care living facilities) as the chosen six participating facilities can adopt our recommended saving measures and see similar results.
CHAPTER 4

CONCLUSIONS

This study was motivated by desire to better understand and quantify water use behaviors by Commercial and Industrial users, a sector that has seen few prior studies. In this project we focused on the problem of nonintrusive monitoring, which attempts to disaggregate water use without using individual meters for every end use. We harnessed the power of smart metering technology to understand the water use behavior of six commercial and industrial users in Logan, Utah. We also inspected how water use might vary from one user to another and how use compares to past residential water use studies. We collected data at monthly, 5-minute, 5-second frequencies and used the monthly billing data to identify potential participating facilities for the study, which eventually were narrowed down to six facilities. 12 smart meters (registers and pulse counters) were deployed to collect data from the 12 city water meters serving six different CII users. High frequency data were collected over a period of 11 months and stored in a local database. The database holds more than 25 million records collected at 5-second frequency which is the longest monitoring period for high frequency water use data that we are aware of for either the residential or CII sectors – the longest monitoring period prior this study was two weeks. We were able to breakdown the total water use into industrial, irrigation, faucet/toilet, humidity maintainer, network test, and shower water use events where we identified individual events based on their volume and duration.
Results enabled us to check the appliance technical performance and compare them to findings from past residential studies. Most indoor water fixtures were efficient and were operating according to the standards. However, retrofitting some indoor water use fixtures could lead to significant saves in water use comparing to residential units since those fixtures are used more frequently inside CII facilities. Outdoor water use varied from 1,000 to 60,000 gal/event depending on the irrigated area which exceeded 20,000 Sqft for one participating facility. LIR estimates for a period of at least two months from all participating facilities were more than one, indicating that the amount of water used for irrigation surpassed what was actually needed for irrigation. Based on the performance of the end uses, we recommended some conservation strategies to retrofit water fixtures used inside the facilities to highly efficient fixtures and having the irrigation system checked for potentially more efficient setups which could result in tremendous water saving for the users.

Hourly water use trends showed assisted care homes had water use variation similar to the residential one with two demand peaks in the morning and in the evening hours.

The GPCD estimates of the assisted care homes and the manufacturing facilities were similar to the findings from Community Systems study (Utah, DWRe (2005)).

Knowing seasonal peaks will allow water managers to accommodate these quantities as well as plan for seasonal variations. This study also proves the effectiveness of non-intrusive loggers and that with the superb data disaggregation
techniques, like the ones employed in this study, end uses can be identified accurately.

The metering system we used and the findings of it can benefit the non-residential water users, Logan City, researchers, and other urban water managers. First: 1) collect high-frequency data to help quantify the timing, volume, and distributions of individual on-site water uses; 2) provide more information about when and how much water is used by different types of commercial water users, summarize existing water uses, identify opportunities to conserve water, and the volume of water that may be saved by conservation actions.
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