Water Sustainability at Worcester Polytechnic Institute

An Interactive Qualifying Project Report
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WORCESTER POLYTECHNIC INSTITUTE
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by

Stephen Couitt, Christopher Preucil, and Alexander Wong

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Approved:

Professor Suzanne LePage, Co- Advisor

Professor Robert Hersh, Co-Advisor

Abstract

This project aims to reduce the amount of water consumed by Worcester Polytechnic Institute through both behavioral and technological changes. To accomplish this goal the project analyzed the quantity of water used in order to identify likely water conserving opportunities. Through conducting a water audit, visual inspections of the current fixtures, and interviews with WPI's facilities, the project was able to identify areas in the highest need of changes, and make suggestions to the institution based on the projects findings.

Executive Summary

The Facilities Department at Worcester Polytechnic Institute (WPI) suggested the pursuit of this project in order to become more sustainable with respect to WPI's water consumption. This Interactive Qualifying Project (IQP) focused on discovering how WPI uses water and proceeded to look for ways to reduce the total consumption.

To get a better understanding on how WPI consumes water, our team conducted a water audit on the existing water infrastructure. For the first step of the water audit, our team interviewed key members of WPI Facilities in order to get a better understanding of the water infrastructure and institutional policies on water conservation. From the Facilities System Manager and Acting Sustainability Coordinator, Mrs. Elizabeth Tomaszewski, we obtained information about how WPI works towards creating a more sustainable campus. This is accomplished through sustainability conferences, involving student groups, renovations and new buildings using green technologies, and surveys that gauge the sustainability on campus. From Mr. Grudzinski, the Chief Engineer, our team discovered there were difficulties locating the water meters. With his help our team was able to physically inspect every building on campus taking pictures, descriptions and latitude and longitude coordinates of the water meters. With this information we created a map in Photoshop depicting all of the locations on campus, with pictures and descriptions on the back, to aid in finding the meters. Also from Mr. Grudzinski we obtained the water billing history. The billing history contains consumption and sewage readings for individual buildings which spanned the previous six to seven years. This was crucial to our project because we were able to gain a better understanding of how WPI is billed, what types of buildings tend to consume the most water and the general campus consumption trends.

Annual consumption of WPI buildings varies depending on the buildings purpose. In recent years residential buildings have seen an increase in water consumption while academic buildings have seen significant decreases. Also, general consumption has leveled off since fiscal year (FY) 2008. Water consumption at WPI follows a general trend of higher consumption during the school year with significantly lower usage during the summer and school breaks. Another trend throughout campus is the drastic consumption drop that took place from FY 2006 to FY 2008. After discussing this trend with Facilities we determined the most likely cause is due to the transition from open water cooling systems to closed systems. This switch significantly reduced the amount of water consumed on campus.

From analyzing the consumption data it is apparent that the largest consumer of water on campus is Gateway Park. Gateway is primarily used for research which in itself leads to high water consumption. Also from the data we know that buildings with dining facilities tend to consume much more water than buildings without.

From the analysis of our data we were able to make some important discoveries about consumption trends. One significant fact is temperature and precipitation have no apparent effect on water consumption. Another finding that we learned from analyzing the buildings is that existing fixtures do not have uniform flow rates. Fixture efficiencies vary from building to building and even within individual buildings themselves.

We compared a LEED certified building, East Hall, to a non-LEED certified building, Daniels Hall. We chose these buildings because they are very similar in amenities. When looking at these buildings we learned that Daniels consumes more water and that East Hall has greener water technologies. Because LEED certification requires more efficient water fixtures, the difference in water consumption is most likely due to one building being LEED certified while the other is not. Extrapolating this one may draw the conclusion that LEED certification results in lower water consumption.

After conducting all of our analysis we were able to not only make recommendations to the school on how to further lower its water consumption, but we were also able to provide a cost-benefit analysis of the suggested upgrades. Through the cost-benefit analysis we were able to determine how much use each fixture will require to pay for itself in the amount of water saved. In general, we found that the lower cost fixtures paid themselves off more quickly, even if the more expensive ones conserved more water. This trend is due to the extremely low cost of water; however, with the price of water rising these fixture upgrades will consistently save more and more money.

In addition to recommending fixture upgrades, we also made recommendations to affect the behavior of the WPI community. While an efficient fixture can conserve water, if the user refuses to operate the device in a sustainable manner there is no telling how effective the upgraded fixtures will be at conserving water. These behavioral recommendations range from placing signs near fixtures to encourage sustainable use, to implementing inter-building competitions to help get the students more involved in the sustainability movement.

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Division of Labor

For this project the team consisted of three team members, Stephen Couitt, Christopher Preucil, and Alexander Wong. Each person contributed to the project in different ways, with Stephen taking the role of the leader. As the leader he not only made sure the team knew what was needed to be done each week, but also acted as the face of the group. Since Stephen is more of a people person than the other two team members, he handled most of the talking to personnel outside of the IQP. Christopher handled most of the edits ensuring the paper would flow and make sense to the average reader. He worked in conjunction with Stephen to ensure the best word choice in sections, and helped to produce the meter map. Finally Alexander handled most of the data manipulation, this ranged from tabulating data into tables to working to produce graphs. Most importantly he conducted the statistical analysis on the data ensuring it was displaying legitimate trends.

1.0 Introduction

Water is an integral part of life on earth; therefore, it is imperative that as a university we recognize that it is a diminishing resource, and work toward creating a more water friendly campus. Promoting water sustainability at the university level, not only preserves the university's surrounding environment, but also helps to create a more sustainability-conscious population. Worcester Polytechnic Institute (WPI) was founded to create and promote the most current advances in science and engineering in ways that are most beneficial to society. Since sustainability is such a large issue in today's world, it only makes sense that WPI work towards creating a more sustainable campus to benefit society. As mentioned in an interview with the university's sustainability coordinator, Elizabeth Tomaszewski, "the biggest concern we have is simply trying to do the right thing for the residents, the students, and sustainability" (Tomaszewski, 2/7/14). WPI has been working to develop a sustainability plan that targets all aspects of sustainability including transportation, energy and water conservation. Our goal is that through examination of the current water systems installed on the WPI campus, combined with the knowledge of what other schools are doing to further water sustainability on their own campuses; we will be able to recommend alterations that could be made both on a technological level and behavioral level to further WPI's ability conserve water and help create a more sustainable campus.

Throughout the country, universities have made significant changes to their campus infrastructure in an attempt to conserve more water and further their sustainability. Through examining some model universities, we were able to identify commonalities amongst the changes that were made; these commonalities provide a standard for what can and should be done to improve water sustainability on a college campus. In addition to the common changes that were implemented, some universities have also implemented unique water initiatives for improving their sustainability. These initiatives provide us with more creative ideas for how to reduce water consumption on the WPI campus.

In order to reduce water consumption at WPI we must first know how much water is being used by the university and how the current water systems function. To learn about the water systems at WPI we interviewed the chief engineer of the WPI Facilities department, William Grudzinski, which allowed us to obtain helpful insight on the current systems, which proved to be essential to the success of our project. Through working with WPI Facilities we also learned WPI's buildings are individually metered and the institution is billed on a monthly cycle. From the meter and bill information we were able to conduct a water audit of campus buildings, to identify the primary water consumption areas on campus. The water audit has shown that the majority of water use comes from residence halls, dining facilities and research labs such as Gateway. Through analyzing the data obtained in the water audit we are able to make recommendations to WPI that would effectively reduce the total water consumption and create a more sustainable campus.

Because WPI is a well-established and long standing institution, a majority of its buildings are several decades old. We believe this creates significant opportunities to reduce water consumption by updating outdated fixtures to newer and greener ones. Even within the last 20 years newer technologies have become available, which have the ability to greatly reduce water consumption. Some of these technologies include dual flush toilets, low-flow showerheads, and water-efficient washing machines. From the data we collected on the existing systems and fixtures currently in place we can show how much water can be saved if inefficient systems are replaced with these newer technologies.

Armed with the knowledge of how much water new fixtures will save, we can make recommendations to Facilities informing them which areas will see the greatest improvement in water consumption. This knowledge will also allow us to provide a cost-benefit analysis to show facilities how long it will take for their investments to pay for themselves and when they will begin to see a profit from the changes. We hope that Facilities will use this information to implement the suggested changes, thus reducing water consumption at WPI and creating a more sustainable campus.

2.0 Background

The goal of this chapter is to provide background information on the current state of water sustainability as it relates to the university setting, such that the reader recognizes the advantages and challenges faced when a university such as WPI wishes to become more sustainable. It begins with examining what other universities have done in an effort to improve water sustainability, discusses the importance of a water audit, how to conduct such an audit, and provides information on what efficient fixtures are available. The chapter than proceeds to examine what WPI has already done, what they plan on doing in the future, and what their outlook is on the importance of sustainability for the WPI campus specifically.

2.1 How Other Colleges are Improving Water Sustainability

When considering water sustainability as it relates to a university setting it makes sense to examine what other colleges are doing in an attempt to create a greener campus; more specifically, it is helpful to examine what these campuses are doing with regard to conserving and sustaining their water environment. Through doing this we will be provided with proven methods of how to create a more sustainable university. With these proven methods we will then be able to determine a course of action for WPI to effectively improve its water sustainability, and create an overall greener campus.

To achieve campus sustainability these universities have made significant changes including renovating existing buildings to implement more efficient fixtures, designing sustainable buildings from the ground up, and educating the surrounding community about sustainable water practices. An effective way of identifying where to focus water conservation efforts is through preforming a water audit of the campus (refer to section 2.3 for specifics of a water audit). The efficient fixtures that schools have chosen to implement include aerators, low-flow shower heads, duel-flush toilets, and high-efficiency washing machines. These fixtures are discussed more in detail in subsequent sections.

2.1.1 Amherst College

Amherst College, in addition to upgrading its fixtures to be more efficient, has installed a Dolphin Water Treatment System. This particular system is designed to treat the water used for cooling the buildings in cooling towers. It is able to reduce the amount of water used at each cooling tower by 15%, thus greatly reducing the overall campus water consumption (Amherst, C, ND). The irrigation system of Amherst College utilizes rain sensors to disable the automatic system in the event of excessive rainfall (Amherst, C, ND). Additionally they have been able to improve the condensation return rates of their steam heating system by 10%, providing an approximate 8,000 gallons of water savings per day; Amherst College was able to achieve this increased condensation return rate through aggressive water treatment, trap maintenance, and condensate line replacements (Amherst, C, ND).

2.1.2 University of Massachusetts Amherst

UMass Amherst focused on renovations to include more efficient technologies, and began utilizing reclaimed water for use in their boilers (Amherst, U, 2013). From these renovations the university saved an average of 10.5 million cubic feet of water which equates to an approximate savings of $400,000 (Amherst, U, 2013). In addition to implementing water conserving technologies throughout the campus, this university has also chosen to implement an Eco-Rep program. This program was created to help increase environmental awareness on campus and promote sustainable behavior (Amherst, U, 2013). It is the job of the Eco-Rep "to 'make sustainability sexy' to fellow students and promote behavioral change at both individual and campus-wide levels" (Amherst, U, 2013).

2.1.3 Cornell University

Cornell University has an organization on campus known as the Sustainability Hub. The Hub, similar to the Eco-Rep program, is designed to promote sustainable practices throughout Cornell's camps. The Hub however has the added responsibility of designing new sustainability initiatives and brining other student groups together to accomplish their sustainability goals (Cornell, 2013). The Cornel campus achieves its sustainability through requiring low flow fixtures in their building standards, using district cooling to cool the campus buildings, and improving the lab practices (Cornell, 2013). The district cooling system is almost completely renewable, this works by utilizing lake-source cooling. This method of cooling works by using the deep already cold waters of Cayuga Lake; through using the colder lake water for cooling, the university is able to eliminate refrigeration equipment (Cornell, 2013).

2.1.4 Duke University

Another school that is making notable efforts to become a more sustainable campus, is Duke University. In addition to installing more efficient fixtures in their campus, Duke has given away free low-flow showerheads and aerators to their employees and off campus students (Duke, ND); through doing this Duke is promoting sustainable water practices, creating a more sustainable community, and positively impacting their surroundings. In addition to installing thousands of low flow fixtures and high efficiency washers throughout the campus, Duke has chosen to add a reclamation pond (Duke, ND). This reclamation pond collects water runoff from

22% of the Duke campus to be used in cooling the campus buildings; it is estimated to save the school 100 million gallons of water a year (Duke, ND).

In an effort to conserve even more water, Duke University conducted a water audit in August of 2012 (Roth, 2013). This audit primarily examined the effectiveness of upgrading water fixtures in six academic buildings (Roth, 2013). It was projected that the upgrades will save duke up to $120,000 a year in water and energy costs, while costing the university $150,000 to implement these changes (Roth, 2013). The water audit provides economic incentive to implement these upgrades, as they will be paid off in approximately fifteen months.

2.1.5 Effective College Sustainability Improvement Methods

Many schools saw improvement in water consumption, through involving students in the sustainability process. As discussed in later sections (section 2.3.3) behavioral aspects is a major part of good water practices. Because of this, raising student awareness on sustainable practices well help decrease water consumption in the university environment. Student groups such as Eco-Reps and Cornell's sustainability hub create a bridge between sustainable practices and the student body. Another common water conservation method is improving the cooling system of the university. Several institutions saw massive water savings by utilizing alternative water sources to help lessen the consumption required to heat and cool their campus buildings.

In the majority of colleges that we reviewed significant water savings were also seen through fixture upgrades. These upgrades typically focused on older outdated models being replaced with newer greener technologies. To determine what fixtures were in need of upgrades some universities took inventories of current fixtures and analyzed the effect certain changes would produce. This is more commonly known as a water audit.

2.3 Water Audit

A Water Audit is an accounting procedure that identifies water usage sources in order to reduce the overall water consumed. By determining the water usage sources the audit highlights misuses, inefficiencies and losses in a water system allowing the auditor to rectify these problems (NRDC, ND). Because the auditor cannot physically fix the problems, they will submit their discoveries to the client with strategies on how to do so. Depending on the institution where the audit is performed, the actual procedure can vary significantly. Our audit is one of a college campus so we will explain the general techniques involved when dealing with a school's building infrastructure. For this particular audit there are three main steps. The first involves pre-audit data collection, the second is an analysis of the water systems and the third step looks for water conservation opportunities and recommendations.

2.3.1 Pre-Audit Data Collection

This is the first and possibly one of the most crucial steps involved in a water audit. It is important because the data collection requires establishing a strong relationship with the audit client which will allow the auditor to collect background information on the facility. Without close collaboration with the client the audit will ultimately fail due to lack of information, cooperation and support. Even if the audit manages to collect enough information, without the client's full participation few of the suggested changes will come to pass (Communications, S. 1999).

To develop a strong relationship with the client the auditor should make contact very early in the process. Once there has been some initial communication, an interview is an effective second step to both gather information about the water system and also help determine what the client wishes the audit to complete. The interview itself should primarily target the above points, but the auditor can also use it to become better acquainted with the client. Some of the questions should inquire about who is the main water provider, how the water is billed and metered, locations of the water meters, how far back the client's records cover, the client's outlook on water conservation, how the water system is maintained and any other question the auditor may wish to ask regarding the water infrastructure (Communications, S. 1999). After the interview the auditor should schedule a meeting to obtain the billing history of the facilities.

How the client has kept record of the billing history will determine how the auditor will proceed with analyzing the data. The best case is that the client has extensive records spanning more than 5 previous years. This will allow for good analysis and is what is needed for a successful audit. If the client's billing data covers only a few years or is missing large sections, the auditor will have to try and obtain the rest of the data from the water provider for the facility. The billing history will contain information about the water consumption on a monthly or quarterly period depending on the size of the institution.

Larger institutions are normally billed on a monthly period where smaller institutions are billed quarterly. A typical water bill will consist of two billing amounts, the water usage cost and the sewage cost. Depending where the facility is located will determine exactly how the bill is calculated. Rates and billing methods vary widely depending on geographical location, causing rates and billing methods to differ from state to state. Generally there is a monthly base allowance volume. This allowance is a set price for a predetermined quantity of water (Kiepper, D. B. ND). Once that allowance has been exceeded water providers charge for the excess water use. They tend to have three different methods for charging. The first and most common is a uniform rate, in which, like its name suggests, water and sewage charges do not change as the water use increases (Kiepper, D. B. ND). The next method is called increasing block structure in which the cost of water increases as water usage rises. This method encourages water conservation more so than the others, due to the continually increasing rates. The final method is called decreasing block structure and is the opposite of the increasing block structure (Kiepper, D. B. ND). In this method the price for water actually decreases as the consumption rate increases. The decreasing block method is less common because it does not support water conservation ideals.

The water provider determines how much water is consumed through the use of meters. Generally there are both water and sewer meters that display the usage, similar to an electric meter. In some cases there is only a water meter so only the usage is measured. Because not every building has both meters the water provider tends to charge only based on the usage readings. The cost of sewage is determined by 100% of the usage reading, but the charges for usage and sewage tend to vary depending on location. In most cases the sewage rate is slightly higher due to surcharges associated with the cost required to purifying the water so it can be safely returned to the environment (Huntsvilleal, ND).

As mentioned the bill is primarily determined by the water usage meter so therefore it is important to locate them. These meters should undergo regular inspection to ensure they are properly functioning to avoid incorrect readings. Creating a listing of the water meters will inform the client further about the water infrastructure. It will also make locating them easier and more time efficient.

2.3.2 Water Systems Analysis

Once the pre-audit information has been collected an analysis of the water systems can be conducted. This step looks at the water consuming devices in order to locate inefficiencies, malfunctioning devices and leaks. The water consuming devices can be divided into two sections, interior and exterior.

2.3.2.1 Interior Fixtures

Interior devices contribute to the majority of water consumption primarily because there are more water consuming devices located indoors. Showers are a major water consuming fixture in the bathroom. On average 25 gallons of water are used per shower. This value varies greatly depending on length of time that the shower is used (Green, ND). Besides reducing the duration of the shower, a low flow head can be installed to decrease the amount of water that is used. Through installing a low flow showerhead water consumption can be reduced by 50%-70% without needing to reduce the amount of time spent showering (Green, ND).

Another water saving device that is widely available is the aerator. Aerators are small devices that can be attached to the end of a faucet to reduce the amount of water that travels through the fixture. This technology works by dividing the solid stream of water leaving the faucet into a multitude of smaller ones. By spreading out the water in such a way, aerators allow less water to cover more area and at a higher pressure, thus reducing the amount needed to clean (Glimer, ND). Besides that, pressure is significantly more important than volume when trying to remove filth from a surface (Glimer, ND). Aerators are also very inexpensive due to the fact that the faucet does not need to be replaced and aerators are easy to install. Other than aerators, sinks that use infrared sensors are another technology that can be used to reduce water waste. By automatically shutting the faucet off when it is not needed infrared sensors significantly reduce unnecessary water consumption.

In addition to low flow showerheads and aerators, replacing high volume toilets with low flow or dual flush toilets reduces the amount of wastewater per flush. Dual flush toilets work by providing the user with an option to use a lower water volume flush (1.1 gallon) for aqueous waste such as urine, and a higher volume flush (1.6 gallon) for solid waste (Arocha, 2013). The effectiveness of these dual flush toilets however, depends largely on the user. If the user chooses a large volume flush when a low volume flush would do, the dual flush feature does not reach the complete water saving potential (Arocha, 2013). Besides toilets, improvements in urinal technologies have also resulted in newer models using significantly less water than older ones. The most efficient urinal models use no water at all; therefore eliminating all water consumed by fixtures in this category. These urinals use an internal trap which is filled with a liquid chemical lighter than urine. The urine sinks below it and is directed down the drain by gravity, eliminating odor from entering the restroom. The benefits of waterless urinals was highlighted in an article published by Vanderbilt University which stated that a water-free urinal can reduce up to 40,000 gallons of water annually when compared to a traditional urinal. This technology can lead to significant water usage reductions when upgrading from older urinal technologies which are known to use between 1.5 and 3.5 gallons per flush (SBW Consulting, 2007).

In addition to replacing fixtures with more efficient ones, it can also be beneficial to upgrade common high water volume appliances such as washing machines and dishwashers. Older washing machine technologies are based on an agitator system which requires large quantities of water in order to loosen dirt from soiled clothes. High efficiency washers use a tumbler system as opposed to the agitator system allowing them to use very little water and still clean clothing (Institute, 2010). High efficiency washers can reduce the amount of water per use by 33% - 80% when compared to traditional agitator washers (Institute , 2010). High efficiency dishwashers also reduce water needed to clean dishes when compared to older models. These newer dishwashing technologies use 3.7 to 10 gallons of water per load compared to the 9 to 12 gallons of older models and use significantly less energy as well (Authority, M. W.R, 2006).

A study presented to the Environmental Protection Agency involving upgrading household fixtures to conserve water clearly shows the significant decreases that will occur. Table 3 shows a comparison of how technologies have evolved over the past 40 years and how efficiencies have increased significantly.

Table 1: Water Usage Rates of Fixtures Over Time

Technology	**Pre-1970**	**1990**	**2000**	**Current Technologies**
Faucet	3.5 GPM	3.5 GPM	3.5 GPM	.5-2.2 GPM
Showerhead	4.3 GPM	3 GPM	2.5 GPM	1.75-.5 GPM
Tank toilet	7GPF	4-5 GPF	3.5-5 GPF	1.6- 5 GPF
Flushometer Toilet	-	-	1.6 GPF	1.6 GPF
Urinal	25% of water by urinals consumed by continuous style, rest by 5 GPF ones	3 GPF	1 GPF	.125GPF-waterless
Clothes washer	3.5 per pound of laundry per cycle		3 gallons per pound of laundry per cycle	14.4gpc
Dishwasher	9 gpc	5-8 gpc	4.7 -6 gpc	3.7gpc

(Antoniou, D, 2010) (Institute, A, 2010) (Vickers, A, 2001a)

Technology for water use has greatly improved over this time period. For example, before 1970, some urinals ran continuously, but now there are urinals that require no water. Table 3 shows the advantages a flushometer type toilet has over a traditional tank type toilet as well as advantages of new dishwashers which reduce the water used by over 50%. The last column of Table 3 shows the low water use for various fixtures that have a sustainability certificate from third parties and are currently used in the plans for new buildings. Most institutions will install low water consumption devices when constructing new buildings in order to save water. (Vickers, A, 2001a). A majority of the technologies employed today have been readily available since the start of the new millennium so it is common to see many buildings built after 2000 using highly water efficient devices.

Another example of how upgrading water consuming devices can reduce water use is shown in Table 4. This table was taken from a study done on single family homes in regard to common devices' daily water consumption.

Table 2: Comparison of baseline and post-retrofit per capita daily use

Category	Baseline (gcd)	Post-Retrofit (gcd)	Difference in Means (gcd)	% Change	Statistically significant difference?*
Bath	3.0	2.8	-0.2	-6.6%	No
Clothes washer	13.9	8.8	-5.1	-36.7%	Yes
Dishwasher	1.0	0.9	-0.1	-10.0%	No
Faucet	10.5	10.5	0	0.0%	No
Shower	12.0	10.7	-1.3	-10.8%	No
Toilet	19.9	9.8	-10.1	-50.8%	Yes
Indoor	60.3	43.5	-16.8	-27.9%	Yes
Other/Unknown	0.1	0.4	0.3	75.0%	Yes
Total	60.4	43.9	-16.5	-27.3%	Yes
Avg. # of Residents per household	2.56	2.52			

*95 percent confidence level

An area to highlight from this study is daily water consumption decreased by an average of 27.3% after water conserving fixtures had been installed. Some significant areas of improvement come from toilets and washing machines which saw consumption reductions of 50.8% and 36.7% respectively (Mayer, 2003).

2.3.2.2 Exterior Fixtures

Though there are fewer exterior fixtures than interior fixtures there are still significant conservation opportunities available. Exterior fixtures mainly consist of irrigation related devices such as sprinklers and spigots. The majority of waste water reduction which can be achieved from this category is due primarily to adhering to good lawn management practices. A simple and often overlooked method that saves water is disabling irrigation systems when it is raining or about to rain. Because it may be difficult and laborious to constantly turn on and off an irrigation system, new technology has been developed to address this problem. Rain sensors can be implemented that automatically disable the system when substantial rain is predicted. These sensors also reactivate the irrigation system once the lawn is in need of watering (Amherst, C, ND).

2.3.3 Water Conservation Opportunities

Maintenance

There are other ways institutions can reduce water consumption besides installing the newest water saving devices. These include proper maintenance and good water practices. Maintaining existing water systems is a crucial aspect when looking to reduce water waste. For example, a leaky toilet usually leaks half a gallon per minute when the toilet not in use, which leads to 21,600 gallons water per month. Comparatively, malfunctioning irrigation systems leak a gallon per minute for a defective head. (EPA, 2013a). All of that wasted water can easily be prevented if the fixtures are properly maintained. This requires regular inspections of the water infrastructure in order to fix leaks soon after they begin. A typical leaky pipe will lose 15 gallons per minute and will often leak a cumulative 151,000 gallons before discovered. (EPA. 2013a), (Vickers, 2001b). A proactive maintenance crew would drastically reduce that value, thus saving the institution money as well as rectifying the drain leaks like these cause on the environment.

Behavior

Unlike maintenance which requires active searches for leaks, good water practices revolve around more water-conscience decision making. Ways to reduce water are everywhere it just requires thinking critically the best ways to do so. A major part of good water practice is based on behavioral aspects which can be difficult to address. The one of the biggest challenges facing proper water practices is that a majority of people do not realize they are wasting water. The human mind reasons in two completely different ways. The first way is based on rationality, where you see something that makes sense, therefore you should do it. This way of reasoning is generally in favor of being more sustainable but it can also be a hindrance. (Agency, M. P. C. 2009). Consider the following example: People realize that they should try to reduce that amount of water they use because it is good for the environment. But if it costs more to use less water and if they are trying to save money, a rational person will generally opt to use the less water efficient methods and save the money instead of water. The second way is unconscious and is dominated by impulses and your senses. This way generally only hurts sustainability. This is because if being sustainable requires any method that is undesirable, subconsciously you will not want to do it. (Agency, M. P. C. 2009). Other than how people reason, another challenge is due to the fact that human behavior is situational. People are driven by what they feel is right and also by what is in their surroundings. When these factors change inevitably behavior does as well. This means the less challenges that are encountered by individuals, the more likely they will attempt to be more sustainable and continue living a sustainable lifestyle. (Agency, M. P. C. 2009).

Irrigation

A specific example of a water saving technique that institutions can employ involves good water practices in lawn management. By planting specific species of grass which uses 75% less water than more common species, institutions can reduce water used for irrigation. (Davis, U, ND). Kentucky Bluegrass is typically chosen for sod because of its aesthetic appeal but this species of grass also has an interesting survival technique that makes it appealing for water sustainability. To grow and flourish grass needs a specific level of watering and if that level is not maintained the grass starts to die. Kentucky Bluegrass has the ability to enter a state of dormancy when water resources are limited. This summer dormancy does not harm the plant and can go a week under these conditions if it isn’t mowed, stepped on, or otherwise disturbed. (Moss, 2013). This allows the grass to survive periods of dry weather where other species would not. (Moss, 2013). However, due to aesthetic reasons it is likely that institutions would choose not to allow grass to enter a summer dormancy stage due to the browning the plant undergoes while dormant. More factors that cause grass to require more watering include fertilizing and mowing. The reason for this is that mowing damages the plant and requires water to repair. Fertilization overrides plants internal regulation and makes it grow regardless of water availability, which also increases water demand (Moss, 2013). These actions stress the plant causing it to use more water regardless if the plant is dormant or not. (Pound, 2012).

2.4 What WPI is Doing

WPI has committed itself to a campus wide sustainability plan in which it looks at ways to reduce the amount of water consumed on campus. WPI's sustainability plan aims to evaluate the university's sustainability in several areas such as power, transportation, dinner services, and water consumption (WPI, 2013b). WPI's first formal and explicit commitment to the principles of sustainability was the creation of the WPI Task Force on Sustainability (WPI, 2013b). The WPI Task Force on Sustainability was created in 2007, since its creation it has coordinated the sustainability efforts of WPI to "ensure the long-term sustainability of the institution's academics, research, community engagement activities, and day-to-day campus operations" (WPI, 2013b, 3).

One way to ensure long-term sustainability of an institution is to continually compare the currant sustainability practices that are in place with the sustainability standards of the time. Each year surveys such as the ones provided by Princeton Review, and the Sierra Club are completed. In addition WPI completed the pilot survey provided by the Association for the Advancement of Sustainability in Higher Education (AASHE) in 2010, which uses the STARS (Sustainability Tracking Assessment & Rating System) survey to assess campus sustainability of colleges. Since the pilot survey was introduced, both The Princeton Review and Sierra Club surveys have since been included in the STARS survey (Tomaszewski, 2/28/14). Through completing these surveys WPI learns what the sustainable standards are for colleges around the country, these standards are raised each year (Tomaszewsk, 2/7/14). A few examples of what these surveys examine are: what a colleges' operations do for sustainability, what sort of efficient equipment is being utilized on campus, the carbon footprint of schools, and water consumption per capita. The standards for what each school has in place are constantly raised because each year schools improve their sustainability, thus raising the bar for other colleges. From this joint collaboration with other universities, WPI would particularly like to implement grey water usage where possible.

In addition to constantly re-evaluating campus sustainability, WPI has also recently implemented an eco-rep program, similar to the program at UMass Amherst. The intent of the eco-rep program is to have peer mentors in all the residential buildings to help promote sustainable behavior (Tomaszewski, 2/7/14). "Studies done by Greeneru show that peer to peer education is much better than other forms of education" (Tomaszewski, 2/7/14). As Ms. Tomaszewski suggested, the reason peer to peer education is more effective in changing behavior is because students are more likely to react to the ideals of their peers, rather than a lesser known person, such as a teacher, telling them how to use water in a sustainable way. Essentially the goal of the eco-rep program is to promote sustainable behavior through peer to peer education. In addition to attempting to alter student behavior, WPI has also implemented the use of newer technologies.

Prior to 2009 the campus used an open-loop cooling system, which after using potable water from the water main to cool the building, the water is immediately disposed of as sewage. By 2009 WPI had completed renovations in all buildings to utilize a closed-loop cooling system (Salter, 2/24/14). The closed-loop cooling system works by reusing the water rather than disposing of it to the sewage line, therefore using significantly less water. This alteration to the campus' cooling system produced significant water savings throughout the campus, as can be seen through the data analysis conducted in section 4.0

Not only does the Recreation Center utilize the use of efficient low-flow fixtures, but the center's roof also collects rainwater for the use in its cooling towers, which in turn lowers the need to use pumped water from the main campus water supply (WPI, 2013b). Through reducing its overall potable water consumption the rain collection system has helped in making the recreation center a LEED certified building; LEED is a program that provides third-party verification of green buildings" (LEED, 2014). The reclamation system of the Recreation Center helps to conserve over 850,000 gallons of fresh water each year (WPI, 2013b, 15).

Despite a growing student population, there has been a steady decrease in the university's total water consumption since 2011 (WPI, 2013b, 15). This decrease in water consumption could possibly be due to the fact that new construction and building renovations always include the installation of low flow fixtures (Tomaszewsk, 2/7/14). This however does not target the inefficiencies of the current systems in place. Only the buildings with alternative reasons for renovations get targeted for water conservation updates; however, this may cause buildings in dire need of more efficient technology to be overlooked. According to the sustainability coordinator of WPI, Elizabeth Tomaszewski, without accurate consumption data, areas that need improvement will go unidentified, and thus will not be able to be fixed. There has been no obvious effort to systematically assess the overall water consumption of WPI and take action based on the collected information (WPI, 2013a). One way of assessing water consumption and identifying areas that need to be fixed is to conduct a water audit of the campus. Because an audit of this nature has not been performed on the WPI campus, our project largely focuses on conducting such an audit in an attempt to identify buildings in need of newer water conserving technologies.

3.0 Methodology

The goal of this project is to analyze how much water WPI is consuming and to develop a plan to reduce the school's overall water consumption. To obtain this goal, our team, in collaboration with the WPI Department of Facilities, performed a water audit of WPI's water systems. The objectives of the water audit were to learn about WPI's current water infrastructure and how much water WPI consumes. The water infrastructure spans all aspects of the water system from the moment it enters the campus to the moment it goes out the sewage line. This includes the existing metering of the buildings as well as the current fixtures in place. From the water consumption information we learned the actual quantities that are consumed in each building and how WPI is billed for this consumption.

From these objectives we were able to review the water consumption of buildings on the main campus and find trends that could explain the behavior of the data. After collecting the usage data we then visually inspected the existing facilities in order to determine what buildings would benefit from fixture renovations. Once we had this information, we then made recommendations to WPI Facilities which explained what buildings would benefit from fixture upgrades. In these recommendations we showed the initial cost to renovate, the return on investment time frames and the resulting annual water savings. In the following section we will describe the methods we utilized to complete these objectives of the water audit and obtain our project goals.

3.1 Water Audit

A water audit is used to determine inefficiencies and leaks in water systems. For our project, we altered a water audit suggested by the EPA to meet our goals (Agency, 2013). Our audit consisted of three major steps, they included: Pre-Audit Data Collection, Water Systems Analysis and Water Conservation Opportunities.

3.1.1 Pre-Audit Data Collection

The Pre-Audit Data Collection was the first step of our water audit. In this part we primarily gathered all of the hard data from facilities which we used to create the foundation of the entire project. This data foundation includes interviews with facilities, water and sewage usages, billing histories and meter locations.

3.1.1.1 Facilities Interview

Interviewing facilities was a crucial starting point for our project. We interviewed the Chief Engineer of WPI Facilities, William Grudzinski, which established a strong relationship with Facilities and ensured that we were able to continue working together to meet our common goal of a more sustainable campus. Once we introduced our project we asked general questions about WPI’s water infrastructure, such as: how the school is metered and billed for water usage, maintenance and renovation methods, etc. For the full interview, see Appendix I.

Mr. Grudzinski asked our group to develop a listing of all the meter locations. This deliverable was planned to be used by both facilities and the water company to make the meter reading process significantly simplified. During the interview we set up further meetings with facilities in which we would obtain the billing histories and plan walkthroughs of the buildings to locate the meters. In those meetings we also scheduled a time that we would be able to obtain the water billing history of the school so we would be able to analyze the usage data.

To acquire a more complete understanding of how WPI views sustainability, we also interviewed the Facilities Systems Manager, Elizabeth Tomaszewski, who serves as the Sustainability Coordinator for WPI. Questions we asked during this interview focused more on how sustainable practices are implemented, and what current initiatives are in place. Additionally we inquired about the institutional beliefs of sustainability and the school's general outlook on improving campus sustainability. For the full interview see Appendix II.

3.1.1.2 Billing History

From a second meeting with Mr. Grudzinski we obtained the water billing history of WPI. The data varied from building to building but generally covered the previous seven years of billing. This allowed us to analyze the data both from an annual and monthly standpoint. From the information gathered from the billing history we were able to determine which buildings have the highest costs associated with water consumption. This provided a means to focus our analysis in order to determine why the associated costs were so high for certain buildings and not others.

3.1.1.3 Water and Sewer Usage

The billing information we obtained from Facilities allowed us to see how much water WPI consumes. To best organize the data we decided to first create a building by building analysis of the monthly consumption rates over a several year period. We grouped buildings based on their primary role in the WPI community. This let us compare buildings with similar functions (i.e. Academic, Residence Hall, Administrative) and see how other factors like capacity and square footage affect water consumption. Due to the decreases in consumption caused by the changes to the cooling systems, the actual amount of years we had complete data varied, but on average we had at least five years of pertinent data. By organizing the data in such a way we were able to perform several different analyses to help us understand data trends. These analyses included seasonal, per square footage, per occupant and building use. Also it allowed us to see how water consumption varies for different building types (i.e., Academic, Residence Hall, etc.). This data also allowed us to determine which buildings we would focus on when doing our analysis. By having all the building data tabulated we were able to see which sets were incomplete or incorrect which let us exclude them from the analysis.

Because the data is not uniform for every building we had to employ various statistical techniques in order to make valid assumptions about the information we had gathered. Statistical tests are used to determine if these differences are likely to be attributed to normal variation inherent in the data. In statistics, data is often referred to as a population, and the average value of the population is called the mean. Various tests are dependent on a threshold called a p-value. This value is the probability of observing averages of a data set deviating from the normal, if in fact it was normal. In the case of comparing water usage from two years, the p-value represents the likelihood that the average monthly consumption would be that different if the two sets were equivalent. This p-value must be chosen prior to testing.

A normal t-test is used to do determine if the population differs from a pre-chosen value. An unpaired t-test compares two data sets and determines if the means are different. A paired t-test uses paired data where every point in one data set corresponds to a specific point in the other set. A paired t-test checks if the differences differ substantially from zero. These t-tests give a t-value. T-values close to zero indicate no difference detected while a t-value far from zero indicates that the averages are different even while the data is in fact equivalent.

A Wilcoxon Matched Pairs Sign Rank Test, or Wilcoxon Sign Rank Test, is similar to the paired t-test. The difference is that the t-test works best with either data in the tens of millions of any distribution or certain types of uni-modal distribution for smaller sets while the Wilcoxon Sign rank test is applicable to any paired data where all differences can be ranked from highest to lowest. The result is a signed rank sum and the farther it is from zero, the less likely a rank sum would be this far or farther from zero if the comparison was between groups of equal means.

Analysis of variation or ANOVA is an omnibus statistical test. When making multiple comparisons, as opposed to a single comparison of a set to a hypothetical mean or two sets to each other, the risk of assuming a pattern, when there is only randomness, increases. It is not very impressive to make 63 tests with a 95% confidence value and come with 4 significant results. ANOVA allows a screening for these situations and prevents one form seeing false patterns merely because one is making lots of comparisons. The test statistic of an ANOVA is an F-value. If this is higher, there is a higher probability of a true pattern.

3.1.1.4 Meter locations

During one of our interviews with Facilities it was asked if we could create a list of meter locations. This list would be submitted both to the water department and facilities to make reading the meters and maintenance of the meters easier. To do this we toured every building on campus and located the meters, making notes of how to find them as well as the latitudinal and longitudinal coordinates. From this information we developed a deliverable which consisted of a campus map depicting all of the meter locations. On the map every meter is labeled with the building name, street address and customer number. On the back of the map there are written directions to help locate the meters with pictures showing where they are located within each room. To create the map we used the WPI campus map as a template and altered it using Photoshop so that it depicted the relative meter locations. The final version of the meter location map can be seen in Appendix III.

3.1.2 Water Systems Analysis

The next major step of our water audit consisted of the water systems analysis. This analysis was conducted on select buildings that we could use as a model to base similar buildings on. During this selection we took into consideration age, size, intended uses and LEED certification. In this step we looked at the actual devices that account for water usage on campus in order to determine water conservation opportunities. These include interior devices, such as common fixtures and kitchen usage, and exterior devices which primarily consist of irrigation systems. We recorded the model numbers of the installed devices to determine the factory flow rates of the fixtures. This in turn let us compare the existing efficiencies of the installed fixtures to new technologies in order to find water conservation opportunities. In this step we also analyzed all of the data gathered in the pre-audit section and looked for trends in the data that can be explained. This analysis allowed us to draw conclusions about water consumption information in regard to leaks, inefficiencies, seasonal variation, different building purposes and other applications.

3.1.3 Water Conservation Opportunities

From the Water Systems Analysis we knew how much water each building uses and the various flow rates for existing fixtures. With that information we compared the existing fixtures to new high efficiency water saving devices to see if there were possible water conservation opportunities. For the replacements that would reduce water consumption, we performed a return on investment analysis looking at the upgrades that have the greatest water saving potential. This shows how long new devices will take to pay off the initial installment and start saving the school money.

Also from the Water Systems Analysis, we reported any malfunctioning or damaged fixtures from the buildings we inspected to facilities. Improperly functioning fixtures result in major water losses and fixing these are an inexpensive way to reduce water consumption.

Other than fixture improvement, behavioral improvements can also significantly reduce water consumption. To address this we developed a plan to increase water conservation awareness in the WPI population. This plan proposed implementing signs and posters promoting good water practices throughout the campus and incorporating good water saving practices into student events. Through these methods we hope to make students and faculty more water conscious, not only while they are on campus but in their home environment as well.

All of these methods were proposed to Facilities following the completion of our project. We submitted our final report to them which included the recommended changes to the water infrastructure with approximate return on investment timescales. We also compiled our most important findings into a presentation that we delivered to Facilities. Once Facilities has all of the information we have gathered it will allow them to implement the suggested changes when they deem possible.

4.0 Analysis

Our analysis of each building on campus consisted of two parts, first we examined the consumption trends of the buildings. To examine the consumption trends we analyzed the consumption data provided by the WPI department of facilities, and to ensure the validity of the data, we performed various statistical tests. We allowed the identified trends to lead us to certain buildings in which we examined the fixtures to determine if we could lower the consumption of the building with fixture upgrades. Due to time constraints we were unable to conduct a fixture analysis for all the buildings on campus. This Chapter provides an in-depth look into the consumption and current fixtures of five buildings on the WPI campus; For the complete consumption data of all the buildings on campus please refer to Appendix IV.

4.1 Residential Hall Building Analysis

Residence Halls make up a large portion of the total water consumption on campus. This is due to the fact that buildings of this type are constantly occupied whereas academic buildings generally only have people in them during the business day. Also residence halls contain different water consuming fixtures such as showers and kitchen appliances, which are not found in academic buildings. Because of these facts the water consumption trends in academic buildings are dominated by sanitation usage.

4.1.1 East Hall

Building Class: Residential
Construction Year: 2008
30 Boynton Street
Customer ID: 01-0531-A00

As seen in figure 1 water consumption in East Hall has a general upward trend from fiscal year (FY) 2009 to FY 2013 with consumption steadily increasing for three years in a row. There is approximately a 30% increase in usage from FY 2009 to FY 2013. One possibility for this upward trend is leaks that have gone unnoticed over time. It was observed during our fixture analysis, that there was a leak that had gone unnoticed for seven days before a quick fix was implemented. A third, and most probable, possibility is due to poor sustainable behavior of the residence within the building.

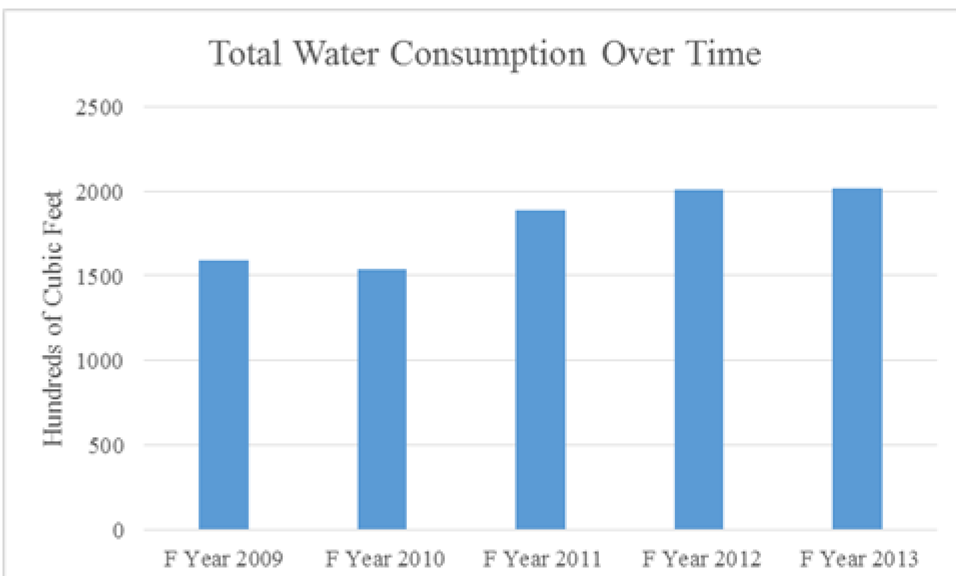

Figure 1: East Hall Yearly Consumption

The water consumption of East Hall follows a reasonable monthly consumption pattern, as seen in Figure 2. When students are present, water consumption is high; whereas, during months that contain breaks, water consumption is lower. This is particularly seen during the summer months, but can also be seen in the bill for January. The bill for January contains the usage from December, during which the students have their winter break. Fiscal Year 2013 has tripled in water usage for June, July, and August compared to the previous years' averages for those months. During this time, East Hall was used as summer housing, a role that was previously filled by Daniels Hall.

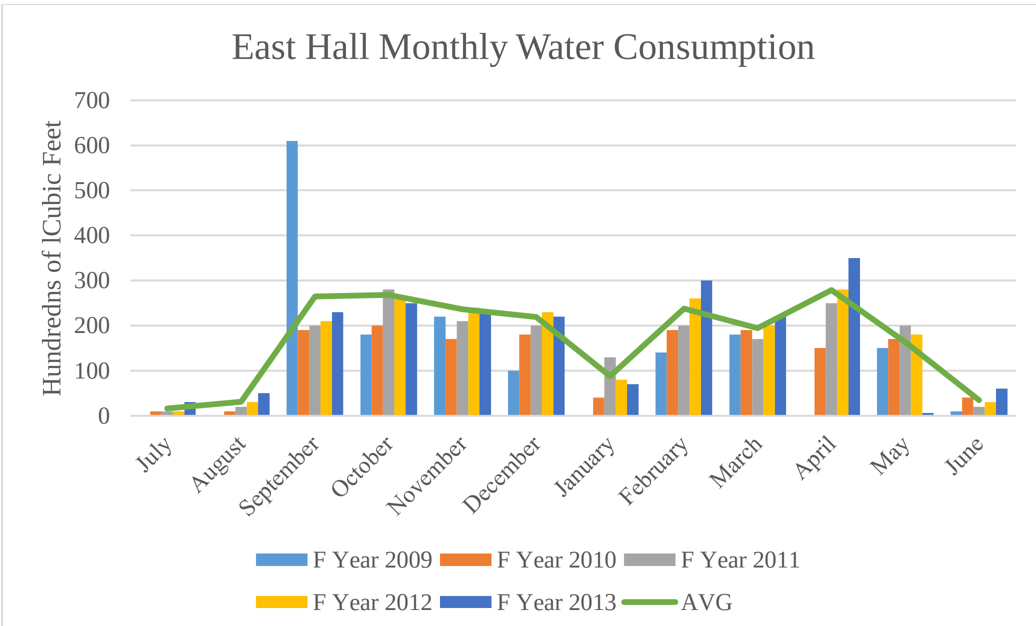

Figure 2: East Hall Monthly Consumption

Typically monthly building consumption stays the same from year to year. Variation of water usage within a year is larger than monthly variation between years. From this information we can conclude that the presence of students has a larger impact on consumption than the variations caused by different student groups, water system breakdowns or other consumption sources. Through examining the data we can see that in any given month the consumption trends upward from year to year. A possible reason for this general trend is the increasing student population at WPI which could be causing an increase in building occupancy. To confirm this we analyzed the building occupancy trends from FY 2011 to FY 2013.

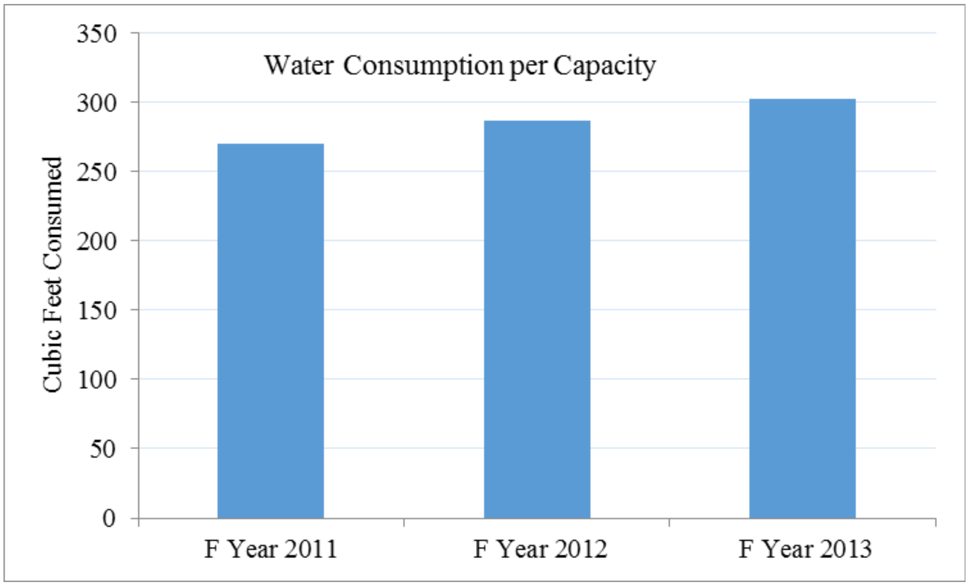

Figure 3: East Hall Consumption per capacity

Through looking at the consumption of East Hall as it relates to the total capacity of the building we see that each year the usage increases. Since the capacity has not changed, either the students have been using more water each year or the actual occupancy of the building has increased each year. While capacity information on the buildings is available, the actual number of residents is unknown. No information about the summer population was found other than the fact that it does exist.

To confirm if the difference in the water usage is a true trend rather than normal variation, an unpaired t-test was run to compare the 12 months of fiscal year 2013 and the 36 months before it. The reason for doing so is that even if the years are in fact equivalent, one might be higher than the other by random chance. Statistical tests are used to prove that the difference is unlikely to be due to random chance and there is something driving the change, in this case it was speculated to be an increase in building occupancy; however, a further analysis of the buildings occupancy must be conducted in order to confirm or deny this possibility, as previously discussed.

The statistical tests confirm that fiscal year 2013 used more than previous years, by approximately 2600 cubic feet on a monthly basis, but at least 712 and no more than 5100 on a monthly basis than earlier years. The reason for this increase is unknown. What is known is that Figure 1 shows this is not an anomaly for fiscal year 2013, but part of a steadily increasing water consumption trend.

Table 3: East Hall Fixtures

Fixture type	Number of fixtures	Flow rate
Maytag Washing Machine	4	-
Toilet	3	1.6 GPF/.8 GPF
Bubbler	2	Open Flow
Urinal	1	1 GPF
Bathroom Faucet	4	.5 GPM
Dorm Bathroom Faucet	128	.5 GPM
Dorm Showerhead	64	2.5 GPM
Dorm Kitchen Faucet	67	1.5 GPM
Dorm Toilet	64	1.6 gallons per full flush/ 1.1 per partial flush

While the fixtures listed in Table 3 are top of the line and it appears there is no room for improvement, East Hall's fixtures might need some maintenance. The water consumption for the building rose steadily for three years in a row by a detectable amount. In the last week of February, one of us who lived in East Hall noticed a couple of defects. The partial flush on the toilet was higher than other duel flush toilets throughout the campus. One of his bathroom sinks failed to drain. The kitchen sink had a small leak, enough for almost ten gallons per week, at least until a quick-fix reduced it to a few drops every hour.

A small case study was performed on East Hall Rooms 314, 315, and 316 to assess how much water is consumed using each device. Students were asked how many times they used each water fixture in their East Hall dorms, and how many loads of laundry were run during a one week period. These three units have 4 people inside creating a study consisting of 12 people. Inside our own dorms over a total of seven days, the toilets received 213 full flushes and 126 partial flushes. Showerheads were used for 950 minutes. The three dorm units used kitchen and bathroom sinks for 150 and 633 minutes respectively. A total of 4 laundry loads were done over this time, which is a bit surprising considering this was done over a week and there were 12 participants involved in the case study. The total amount of water consumed by the twelve residents over seven days was 3,941.9 gallons. This value can be broken down into the following fixture categories': 542.4 gallons from toilets, 2375 gallons from the showers, 1024.5 gallons from faucets, and an unknown amount of laundry usage.

There is not much room for improvement within East Hall. All of the fixtures are among the most water efficient fixtures through the campus. The purpose of looking at the East Hall fixtures is to get an idea of what the idealized usage would be. While the fixtures themselves are fine, East Hall's water consumption rose three years in a row, and as previously described this is not a fluke. While there is no evidence to form a decisive conclusion, there is the possibility that something needs maintenance or it will consume more than the nominal amount.

4.1.2 Daniels Hall

Building Class: Residential
Construction Year: 1963
Customer ID: 12-098-000

When looking at the annual water consumption of Daniels Hall there are a few points that can be made. The first is that FY 2008 is significantly higher than the other years that we have data for. This is most likely due to WPI upgrading the cooling system from an open system to a closed system (as discussed in section 2.4). After FY 2008 the average annual consumption has been 3125 hundred cubic feet. The annual consumption has increased every year since FY 2010. The student capacity of Daniels Hall was increased after FY 2011 when all the rooms were changed from doubles to triples. This could explain why consumption is higher in FY 2012 and 2013.

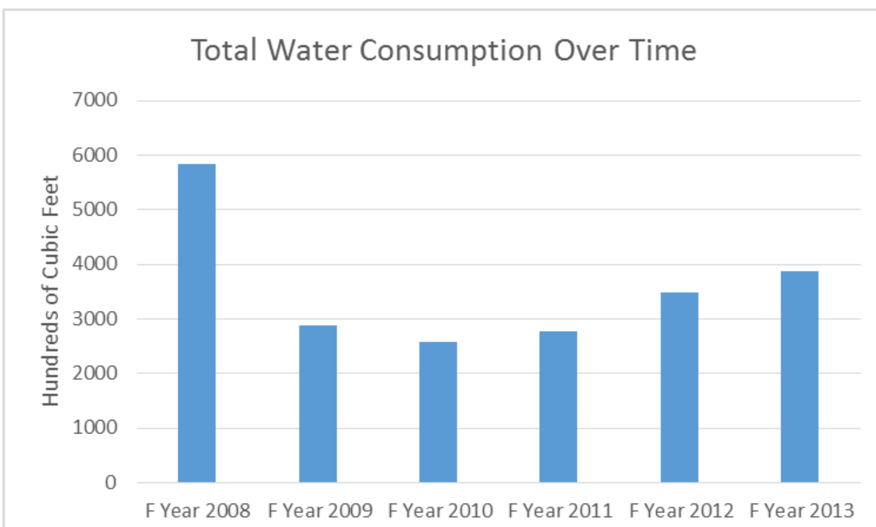

Figure 4: Yearly Water Consumption of Daniels Hall

From the monthly water consumption it is apparent that during the academic year water consumption is higher. Water usage drops off during the winter and summer break and consumption increases during the semester. This is because the majority of water consumption is due to residential use. Daniels Hall also has a laundry facility which is used by students living in

Riley and Morgan Halls which would account for some of the consumption during the academic year. It is important to note that there is some consumption during the summer months which could be due to summer programs and conferences. The conferences are usually staff meetings but some of the programs have students living in the dorm during the summer. This explains why the summer usage is more than what would be expected by office staff alone.

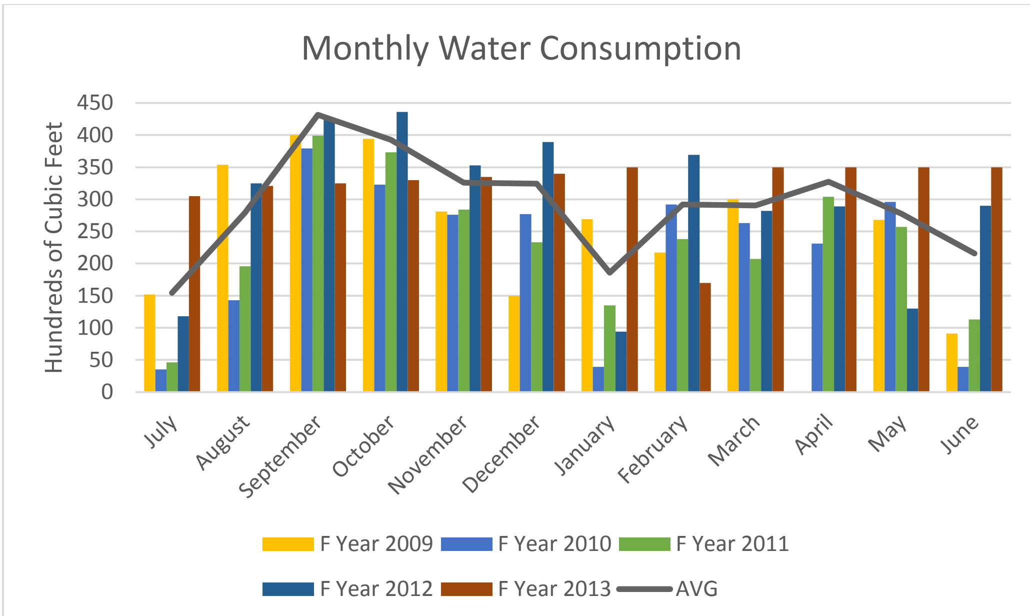

Figure 5: Monthly Water Consumption of Daniels Hall

Per capacity usage is the total water usage divided by the number of people that residential services will allow to live in the particular building. However, only total water consumption and capacity of recent years are known. When looking at the water consumption per building capacity it is apparent that the consumption is increasing even though the capacity has remained the same in recent years.

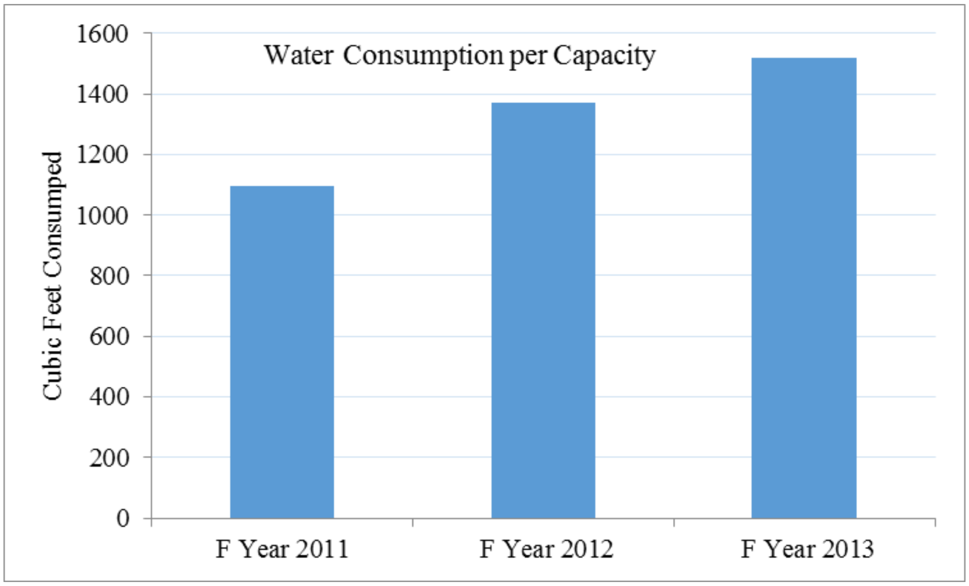

Figure 6: Daniels Hall Water Consumption Per Capacity

Capacity of the building was increased significantly after FY 2011 but the occupants used more than in the previous years. This tells us that the increases seen in FY 2012 and 2013 must also be due to the residents water consumption behavior and not solely due to the fact that capacity of the building was increased during these years.

Table 4: Fixtures in Daniels Hall

Fixture	Quantity	Flow Rate
Bathroom Sinks	36	No aerator – 2.2 GPM
Toilets	36	1.6-3.5 GPF
Urinals	3	1.0-1.6 GPF
Showers	27	1.5-2.5 GPM
Water Fountain	8	Open Flow
Washing Machines	15	4 Gallons/ft^3

Because Daniels Hall is an older building, a majority of the installed fixtures are outdated and therefore, not the most water efficient fixtures available. Almost every sink in Daniels Hall has an aerator and the installed aerators operate at 2.2 GPM. There were a few sinks which were missing aerators but the majority had one. Note that the most efficient aerators operate with flow rates of 0.5 GPM, which use over four times less water when compared to the 2.2 GPM models. Also Daniels currently has 26 showers installed with flow rates of 2.5 GPM and one shower with a rate of 1.5 GPM.

There are 36 toilets, each one with a flushometer installed; however, none of the installed toilets have a duel flush option. Also there are three urinals in Daniels but none are located in the residential part of the building. This is surprising seeing how over 5/6ths of the building is male. Urinals would offer significant water savings due to the fact that none of the toilets had a low-flow flush option, causing large quantities of water to be wasted.

The fixtures that add to the water consumption but are not located in the bathrooms are the water fountains and washing machines. Daniels has eight water fountains. On a good note all of the washing machines are extremely efficient and the installed models have the lowest water consumption of the industry.

4.1.4 Residential Inter-building Analysis

Examination of the various buildings provided insight into how features of each building affected its water consumption. When looking at the consumption trends of residential buildings on campus we compared Morgan, Daniels, and East Hall. As seen in Table 6 Morgan is the only Hall which contains a dining facility, and East Hall is the only LEED certified building. As seen in Table 5 every annual total for Morgan Hall is significantly higher than Daniels Hall, except fiscal year 2013, leading to the obvious conclusion that dining halls consume large quantities of water. To be considered a large difference in consumption, the difference must be greater than or equal to the difference between a LEED certified building and a non-LEED certified building containing similar amenities; such as the difference between Daniels and East Hall.

Table 5: Annual Usages of Select Residential Buildings (100 cubic feet)

Fiscal Year	**2011**	**2012**	**2013**	**AVG**
East Hall Total	1890	2010	2016	2000
Daniels Hall Total	2785	3499	3876	4782
Morgan Hall Total	6230	5037	3710	5224

Table 6: Features of Select Residential Buildings

Amenity	**Laundry**	**Dining Hall**	**Office**	**LEED**
East	Yes	No	Yes	Yes
Daniels	Yes	No	Yes	No
Morgan	No	Yes	No	No

The statistical tests show that Daniels Hall consumed between 51.95 and 160.43 hundreds of cubic feet per month more than East hall. Indeed this shows that East Hall is more water efficient than Daniels Hall. From the comparison of the features of each resident halls, it is thought that the reason for this difference lies in the fact that East Hall is LEED certified, and thus contains very efficient fixtures. These efficient fixtures in East Hall offer one possible explanation as to why the building has lower water consumption than Daniels.

Note that this doesn't specifically mean that LEED makes a difference. All the tests proved is that East Hall uses less water than Daniels Hall by a detectable amount. The tests never reveal why it consumes less. It is possible that the people living in East Hall during the analyzed years were more conservative with water than those in Daniels. However, the behavior of the occupants is not known. East Hall is an upper-classmen residence hall, only recently being available to second years and third years, while Daniels Hall is strictly inhabited by first year students. East Hall dorms do have kitchenettes, which contributes to water consumption involved with dining activities. Daniels was also built in 1963 where East was finished in 2008. This significant difference in age could account for some of the higher consumption in Daniels. Older buildings tend to have more leaks and infrastructural issues due to general aging. East being a relatively new building does not have to worry about these concerns thus the majority of consumption is not likely due to leaky infrastructure. While all of these are indeed possible ways East Hall ended up consuming less water, they have not been confirmed as the cause of lower water consumption. In contrast, the fact that East Hall is LEED certified is a known fact. Residential services give anecdotal accounts as to how sustainable East Hall is, so it is a reasonable conclusion that meeting the requirements to be LEED certified is a contributing factor to why East Hall consumes less water than Daniels Hall.

4.2 Academic Building Analysis

Academic buildings have significantly different trends with greater variation when compared to residential buildings. This is primarily due to the fact that water consumption in dorms is dominated by residential use whereas academic buildings have various other consumption sources that are not strictly limited to the school year.

4.2.1 Olin Hall

Building Class: Academic
Construction Year: 1907
Customer ID: 01-0364-000

From the water consumption data, we determined that water consumption has declined radically since 2007 and after FY 2008 has leveled off to an average of 977 hundred cubic meters annually. This decrease is most likely due to the installation of closed water cooling system which reportedly was completed for all campus buildings by FY 2009 (as discussed in section 2.4). There is a significant increase in consumption during FY 2011 but reasons for this are unknown.

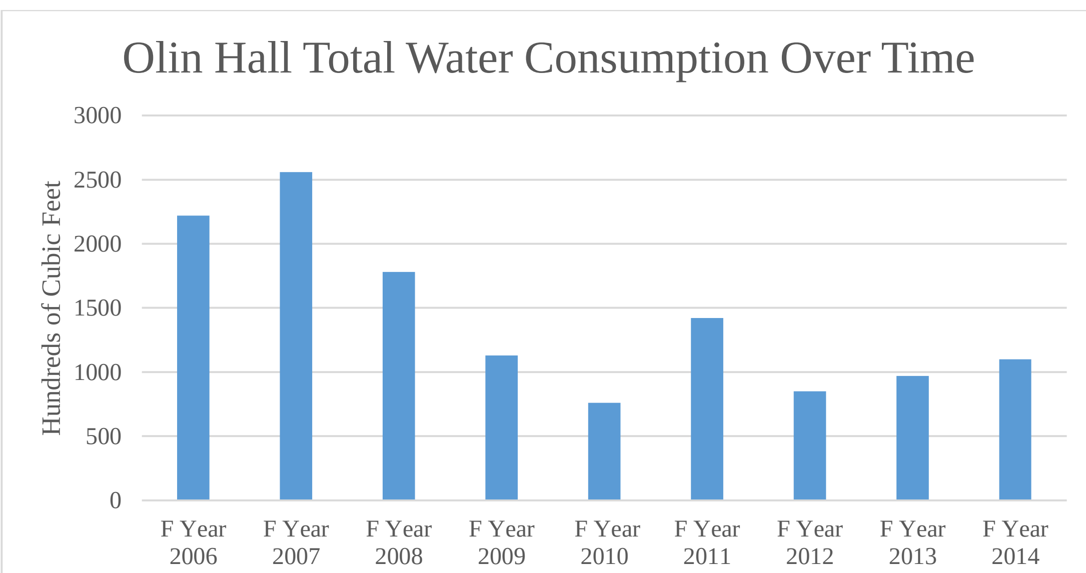

Figure 7: Yearly Consumption of Olin Hall

Unlike most buildings Olin has very low water consumption from December to April and high consumption from May to November. This trend is strange because it does not seem to follow the same high consumption during the academic year and low consumption during breaks trend of other buildings. The water consumption does seem to vary with the changing seasons, increasing during the hotter months and the opposite for the colder ones. It is known that the fountain draws its water from Olin so this is a possible explanation for increased consumption during the warmer months. The fountain is run from mid spring to mid fall which is when the majority of water consumption occurs. The fountain does recycle the majority of water that is used and the losses that would come from this source would be due mainly to evaporation and splash loss. These losses are not significant enough to be the only factor that causes the trends that are seen in the data.

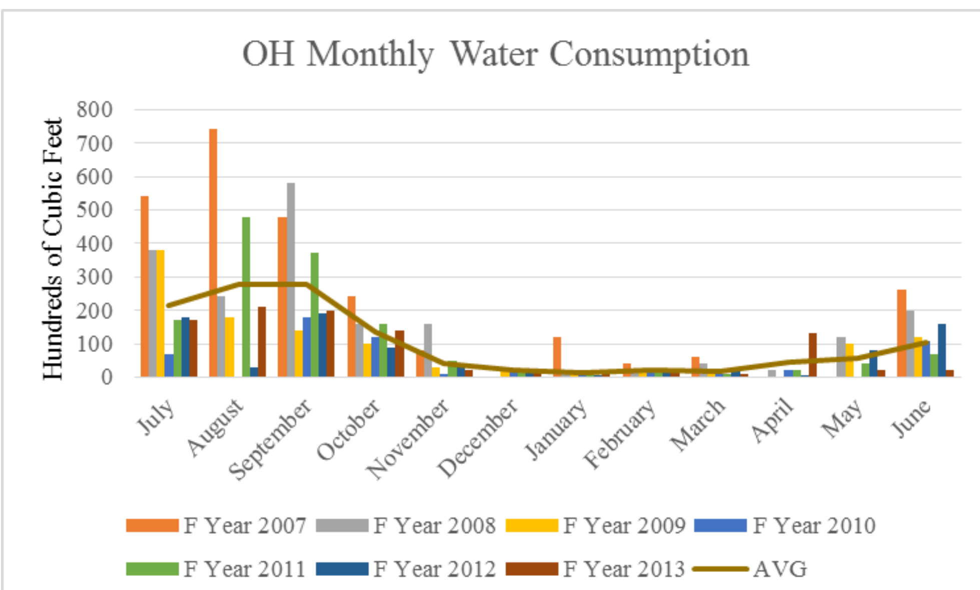

Figure 8: Monthly Consumption of Olin Hall

Also according to the head of the physics department, Professor Germano Iannacchione, Olin Hall is generally busier during A and B terms due to the large quantity of freshman that are taking prerequisite physics classes which could explain the higher trends during this period. From our current knowledge we cannot definitively say if the irrigation for the surrounding greenery is taken from Olin but if it is it could be a viable explanation for increased trends during the summer months.

Table 7: Olin Hall Fixtures

Fixture	Quantity	Flow Rate
Bathroom sink	13	.5-2.2 GPM
Toilet	12	1.6-3.5 GPF
Urinal	7	1.0-1.5 GPF
Shower	1	2.5 GPM
Water Fountain	3	Open Flow
Laboratory Sink	10	2.2-Open Flow
Laboratory Spigot	62	Open Flow
Chemical Shower/Eye Wash	1	NA
Maintenance Sink	1	Open Flow

From a fixture standpoint Olin Hall is in need of some updates. In the bathrooms most sinks do have aerators to conserve water. Unfortunately some of these aerators are not up to date and have very high flow rates. The installed aerators vary between .5 and 2.2 gallons per minute (GPM) with the majority in the 2.2 region. If all of the existing sinks were fitted with .5 GPM aerators total water consumption from sinks is projected to decrease by 64.3%.

In Olin there are 12 toilets all with flushometers installed. None of the existing toilets have a dual-flush option either. The actual flush values are unknown but we do know they can vary between 1.6-3.5 GPF. We can recommend standardizing the flush amount to the lowest GPF of 1.6. By switching to the 1.6 GPF model only the internal assembly of the flushometer has to be replaced and not the housing which is significantly more expensive. Installing dual flush models can also conserve water, but this is a more expensive option.

Urinals run into the same issue as the toilets because they utilize the flushometer technology as well. For the urinals the lowest flow relief and diaphragm assembly uses 1.0 GPF which is recommended for the greatest saving potential. In Olin specifically the urinals are extremely old models and are in need of an upgrade. The greatest water savings would come from switching to waterless models which would eliminate the water consumption from this category completely.

Olin has a long history as a laboratory building and because of that it has a large quantity of lab water fixtures. Olin has 10 lab sinks and very few of them have aerators. Also Olin has approximately 62 lab spigots. These spigots all function correctly, but most are never used. Some spigots on the first floor have aerators installed but the majority of the spigots in the building do not. For the greatest water savings, it is recommended that aerators be installed on all lab sinks, but only the heavily used lab spigots.

Though Olin is an academic building it does have one shower. This shower does not get significant use but there is still minor water saving potential by replacing the existing showerhead with a more efficient model.

4.2.2 Salisbury Labs

Building Class: Academic
Construction Year: 1913
Customer ID: 01-0368-000

In examining the total water consumption of Salisbury Labs over time it is evident that the building has greatly reduced its water consumption since fiscal year 2006. Focusing on more recent years, 2009 and on, it appears as though the consumption of this building has leveled out to average an approximate usage of 500 hundreds of cubic feet per fiscal year. Through our discussions with the WPI Facilities department, we found that installation of closed water cooling systems had been completed for all buildings by FY 2009; this new cooling system is the reason for the drastic decrease in water consumption seen between the years of 2006 and 2009. In the case of Salisbury Labs, one staff member reported that he remembered Salisbury Labs completed the change in the week after A term in fiscal year 2007. Unfortunately there are no records of when this change was completed but based on the data it seems that this is a reasonable completion time for the renovation.

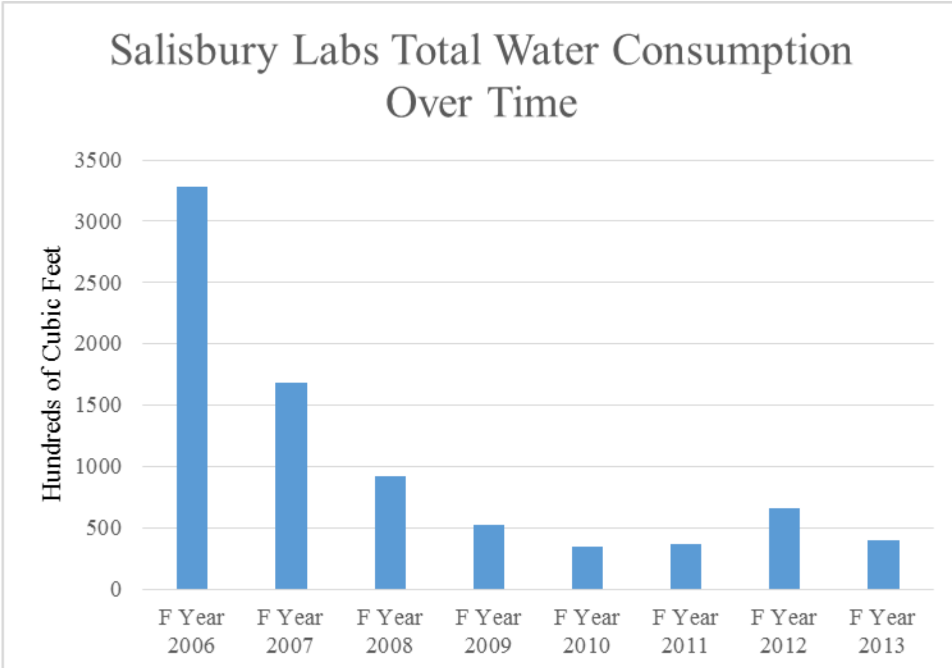

Figure 9: Salisbury Labs Yearly Water Usage

Because of the extremely high water consumption caused by the open water cooling system prior to fiscal year 2009, we focused our monthly analysis on data provided for years after the cooling system upgrade to ensure a representation of data pertinent to our project.

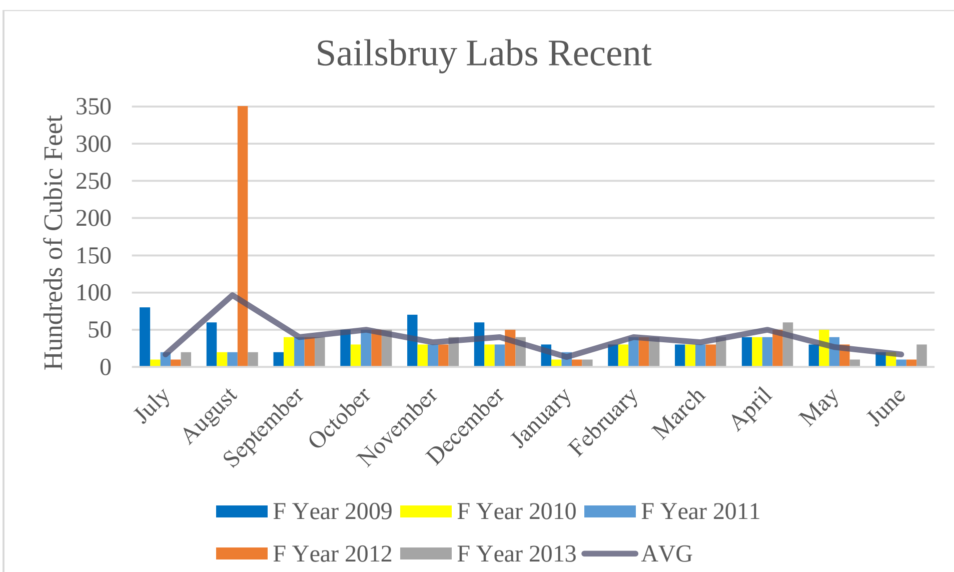

Figure 10: Salisbury Labs Monthly Water Consumption

According to Figure 10 we can see that Salisbury Labs follows the general monthly trend that most buildings on campus follow, which is a lowered consumption during months that contain academic breaks, in which students leave the campus. This makes sense as Salisbury Labs is not utilized for research, but rather mostly utilized for its available classroom space.

Table 8: Salisbury Labs Fixtures

Fixture	Number of Fixtures in Building	Fixture Flow Rate
Faucet	5	0.5 GPM
Faucet	11	2-2.5 GPM
Urinal	9	1-1.5 GPF
Toilet	16	1.6-3.5 GPF
Water Fountain	5	Open Flow

In conducting a fixture analysis of Salisbury Labs, we excluded the greenhouse and bio-lab fixtures as they were restricted areas and we could not gain access. During our analysis it was found that there are a total of 16 faucets throughout the building capable of conserving water (i.e. not lab faucets). Of these 16 faucets, five of them are already operating with a 0.5 gallon per minute (GPM) aerator, thus leaving 11 faucets to be upgraded to more efficient aerators. These 11 faucets are currently operating at flow rates ranging from 2.0-2.5 (GPM), if they were to all be upgraded to 0.5 GPM aerators, combined flow rate reduction would equate to 19.1 GPM.

In addition to the faucets, nine urinals were identified with a recommended operating flow rate of 1 gallon per flush; however, it is possible that the diaphragm in the flushometer is set to 1.5 GPF To conserve water with urinals it would be recommended that all the urinals throughout the building be upgraded to no-flush urinals, thus saving a gallon of water each time an individual urinal is used. We were also able to identify 16 toilets throughout the building, seven of which had a recommended flow rate of 1.6 gallons per flush, the other 9 toilets did not have a recommended flow rate printed on the fixture, so we assume that they operate at similar flow rates; however similar to the urinals these may have diaphragms which allow up to 3.5 GPF to be used. Of the 16 toilets identified four of them were equipped with a dual flush mechanism, which if used properly emits a .6 gallon flush for liquid waste, and a 1.6 gallon flush for solid waste. Unfortunately these duel flush mechanisms were only installed on toilets in the men's bathroom on the fourth floor, which is perhaps one of the lowest trafficked bathrooms in the building.

In addition to the fixtures identified in each bathroom, Salisbury also contains five water coolers throughout the building. Unfortunately water coolers do not report a flow rate, but rather an operational pressure; however, it is unlikely that much water could be saved through upgrading to newer water fountains.

4.2.3 Gateway Park

Building Class: Research
Construction Year: 2007
Customer ID: 14-0161-B00

Gateway is one of the highest water consumers out of all of the WPI buildings. A good representation of this is the annual consumption in FY 2011 which totaled over 1 million cubic feet. Because Gateway has such high consumption values, it should be noted that even small savings in efficiencies will result in large savings of water. Fortunately, water consumption has been decreasing since the high of FY 2011 but recent consumption is still in the millions of cubic feet.

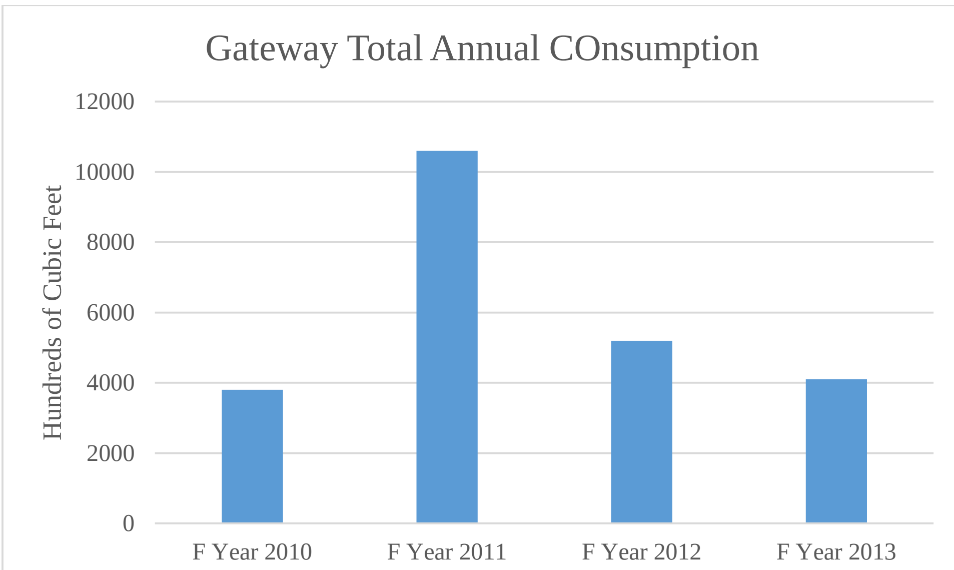

Figure 11: Gateway One Yearly Water Consumption

When looking at the monthly water consumption there appears to be no discernable trends. Consumption peaks at the beginning of the academic year and then fluctuates over the rest of the fiscal year with a common low point in March. Most years have a typical monthly consumption with a number of outliers in both directions, rather than a continuous variation like most other buildings. Any other trends could be due to either outliers or poor resolution of the measurements. One important note is that the data for Gateway has been rounded to the hundreds place for all values. This is strange because no other building is rounded so severely and this could account for some of the noise that is seen in the data represented below.

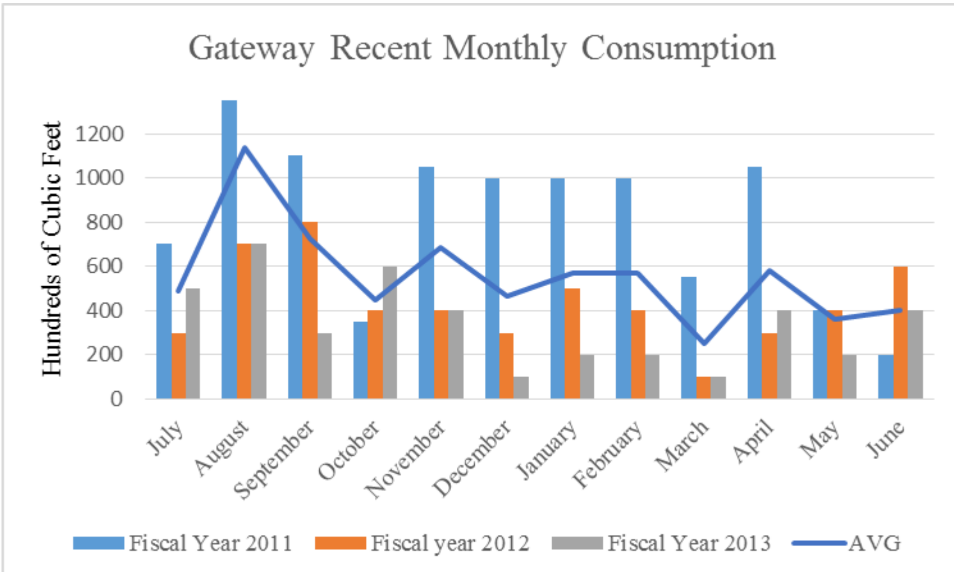

Figure 12: Gateway One Monthly Water Consumption

There are a couple of details that should be noted. Gateway Park is a complex containing multiple buildings, but WPI only pays utilities on Gateway One, the largest building. This is the major biological and medical research building which is not only occupied by WPI but by other businesses as well. An important point to mention is Gateway One's data has low precision. Either the water company is only estimating water usage, or the data was truncated when transcribed. Low accuracy data can obscure a true conclusion that would have been discovered with better records.

Because of the handicap caused by low resolution data, most of the apparent trends in the graphs cannot be stated to be true. The only seasonal trend that can be said with some confidence is that in a given year, Gateway does not consume much water in March. Besides the consumption in March, there is relatively little that can be said in regard to trends for monthly consumption. Two more general pieces of information can still be determined from Figure 11. One is that the water usage in this building has fallen significantly. The other is that a lot of water is consumed by this building, and in fact Bill Grudzinsky, the chief engineer of the WPI Facilities department said it was the largest water consumer on campus. The larger consumption is evident when comparing Figure 11 to the raw data of other buildings, which can be found in Appendix IV.

Table 9: Gateway One Fixtures

Fixture type	Number of fixtures	Flow rate
Faucet	32	.5 GPM
Faucet	5	2.2 GPM
Toilet	32	1.6 GPF
Urinal	8`	1 GPF
Drinking Fountain	6	N/A

Although this list does not contain water consuming lab equipment, it is very likely most of the water being used comes from said lab equipment because Gateway One consumes on such a different scale of the academic buildings. For example, even if Salisbury Labs's bathrooms consumed thirty times more water, Salisbury would still consume less than Gateway's actual consumption. As for the fixtures that can be improved, the ones existing are already efficient and the only possible room for improvement is upgrading the toilets to have duel flush flushometers.

4.2.4 Academic Inter-building Analysis

Looking at these academic buildings, one might want to compare their water uses. This time, the groups in the analysis were buildings instead of fiscal years. The statistical tests show that Salisbury Labs consume 33.7 to 54.66 hundreds of cubic feet less water per month than Goddard Hall. In comparison to Atwater Kent, Salisbury uses 11.097 less to 9.783 more units of water, which means there is no detectable difference. Finally, Salisbury Labs uses 16.44 to 37.32 hundreds of cubic feet more water monthly than Higgins Labs.

Table 10: Academic Building Yearly Water Consumption (hundreds of cubic feet)

Building	F Year 2011	F Year 2012	F Year 2013	AVG Total
Salisbury	370	731	400	712
Olin	1420	824	970	1189
Atwater Kent	372	606	412	544
Higgins	371	301	330	364
Goddard	1520	1000	1090	1385

Table 11: Salisbury Labs Comparison to Other Academic Building

Comparison	Conclusion
Salisbury Labs vs Higgins Labs	Salisbury Labs uses more water
Salisbury Labs vs Goddard Hall	Goddard Hall uses more water
Salisbury Labs vs Atwater Kent	No detectable difference
Salisbury vs Olin	Olin uses slightly more water

In a nutshell, Salisbury Labs consumes more water than Higgins, less water than Goddard, and about the same amount of water as Atwater Kent. The relation to Goddard Hall is understandable because Goddard Hall has more active labs than Salisbury Labs.

It was later determined that Olin Hall would make for a good template for comparison with some of the older buildings. The statistical tests show 1.918 to 93.208 hundreds of cubic feet more water is consumed on a monthly basis compared to Salisbury Labs. The result of Olin consuming more water than Salisbury is quite surprising due to the fact that Olin is both smaller and has lower traffic than Salisbury.

A qualitative look at the bathrooms suggest the bathrooms on the bottom floor of Salisbury Labs receives as much traffic as Olin Hall does throughout the building. The assumption that most of the water consumed by Olin is due to bathroom traffic is in direct contradiction to its summer consumption. As previously discussed, this is a huge surprise because the building has almost no use during the summer. The assumption was that in academic buildings most of the water usage would be in bathrooms, which means the building consumption should be related to traffic. In Goddard Hall, that assumption was relaxed due to the laboratories. There is no obvious reason why the physics labs in Olin Hall would use water, as it became apparent upon inspection, that it was obvious most of the lab sinks functioned but were no longer used regularly.

4.3 Historical Climate Analysis

Because variations in temperature and rainfall occur from year to year we wanted to ensure that water consumption was not greatly affected by this. Buildings at WPI were once cooled by open water systems but these systems were all replaced by FY 2009 with closed systems (Refer to section 2.4). It is then known that in years before FY 2009 temperature affected water consumption because water was used in cooling the buildings. But do temperature and rainfall otherwise have an effect on water consumption? This part of the analysis will, in all years after the open water cooler systems were removed, look for trends between higher temperatures, lower rainfalls and water consumption. To do this we looked up the historical monthly climate for the Worcester area so we could look for trends. Because only warmer months have the potential to significantly affect consumption we focused on the summer months. To ensure that the analysis was successful we selected buildings that have very high consumption during these months. These buildings include Olin Hall and Goddard Hall.

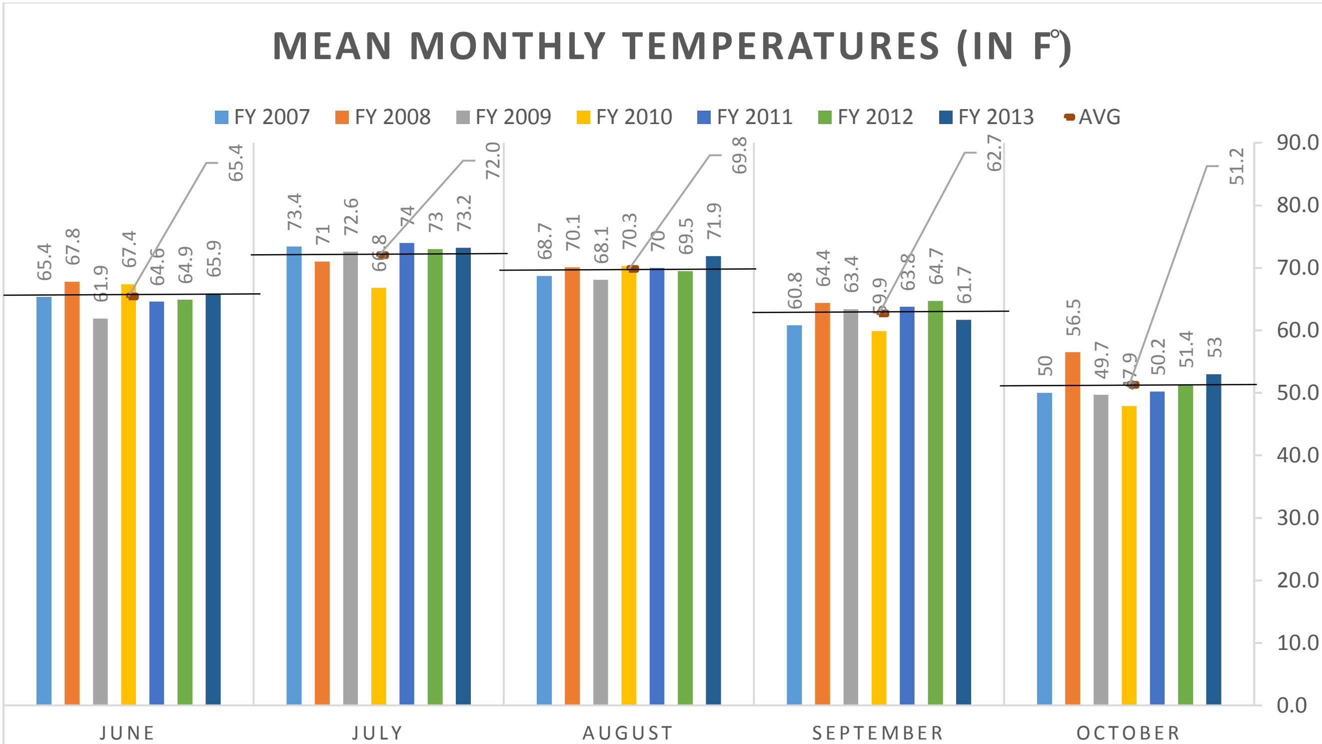

Figure 13: Average Monthly Temperatures for Worcester

In Figure 13 the monthly average is represented by the black lines. It is clear to see that the temperature almost never deviates more than 2.5 degrees from the average temperature. This shows that there is relatively little temperature variation from year to year. For temperature to be a reason for increased water consumption one would expect to see that years that have higher monthly temperatures would have higher consumption for those months, this is not the case. July has the highest average temperature so if higher temperatures caused greater water consumption one would expect July to have the highest consumption. Both August and September have higher average water consumption than July in Olin and Goddard Halls. On average August is only 2.2 degrees cooler but September is 9.3 degrees cooler yet still has higher consumption than July. If higher temperatures truly caused higher consumption then one would expect July to consume more water than both August and September but it does not.

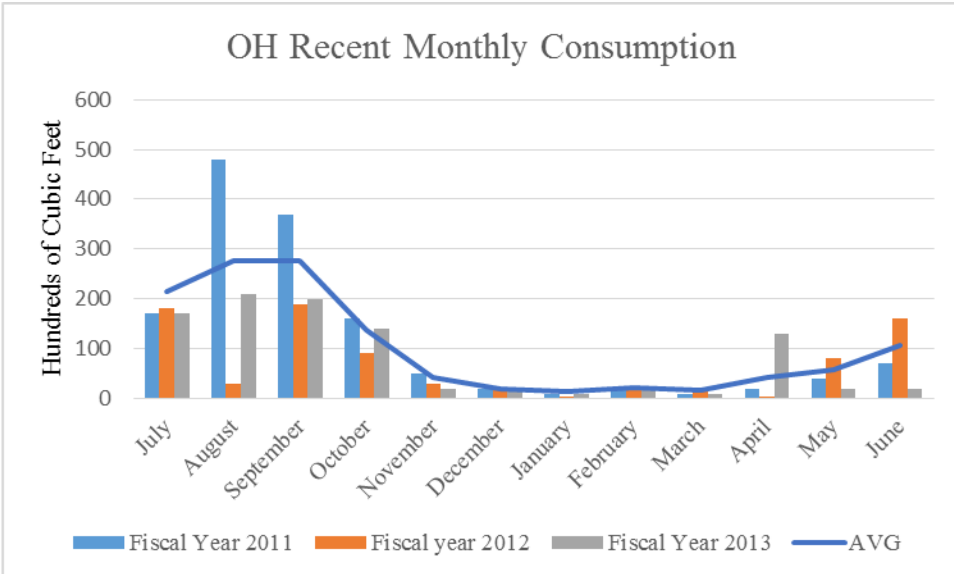

Figure 14: Olin Hall Monthly Water Consumption

Even though there is little temperature variation from year to year, the consumption data can further prove that temperature has little effect on water consumption. When looking at Olin Hall's consumption data for August and September there are a few years which stand out. Fiscal Year 2011 has very high consumption for these months but the highest consumption once again does not coincide with the highest temperature.

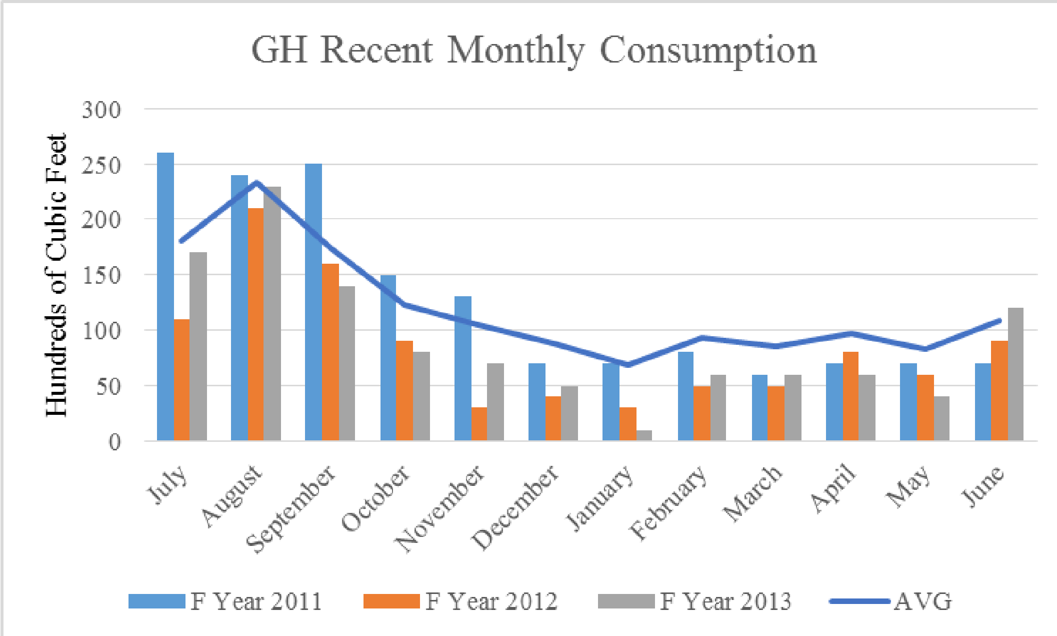

Figure 15: Goddard Hall Monthly Water Consumption

Similar trends can be seen in Goddard Hall regarding high-temperature months and water consumption. This information shows that higher temperatures do not directly relate to higher water consumption.

To evaluate precipitation's impact on water consumption we looked up the rainfall data as well. Just like in the temperature part of this analysis we focused on the warmer months where rainfall would be considered to have a greater impact. The reason behind analyzing the precipitation relies on the fact that we do not know if minor irrigation systems share meters with buildings. Given the fact that we have no knowledge about the irrigation systems we cannot rule them out as a possible water consumption source. With this reasoning one would expect that lower rainfall would result in higher water consumption.

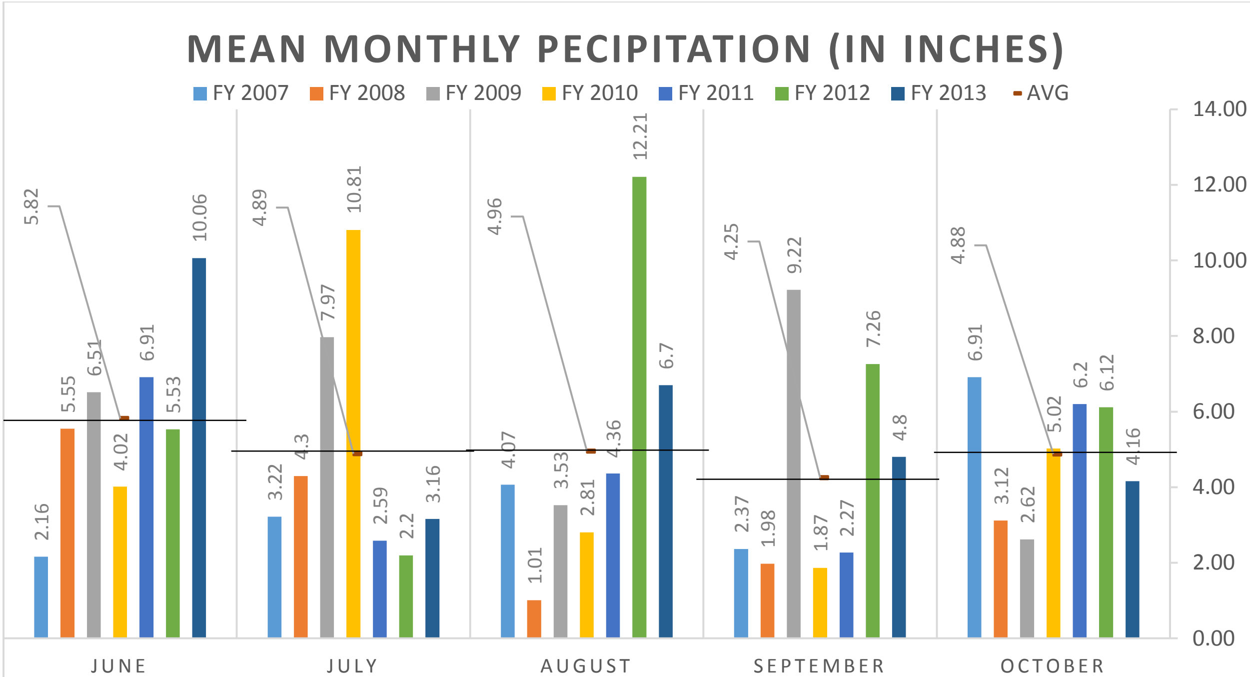

Figure 16: Monthly Rain Fall for Worcester

The month historically with the lowest rainfall is September, while July, August and October all have roughly the same average rainfall. In both Goddard and Olin Hall, July, August and September all have high consumption values but October is relatively low compared to the others. June also has the highest average rainfall and consumes the least water of the warmer months. From just this information there does seem to be a correlation between rainfall and water consumption.

4.4 Cost-Benefit Analysis

Through preforming a complete analysis of particular buildings we were able to identify fixtures throughout the campus that if upgraded would help to reduce the overall consumption of water on the campus. The fixtures recommended for upgrades are discussed with further detail in section 6.1. Using equation 1 we were able to calculate how long it would take for the suggested fixtures to pay for themselves in savings due to reduced water consumption.

Equation 1: Time to Return on Investment

$$\frac{Cost\ of\ New\ Fixture}{(Old\ Flow\ Rate - New\ Flow\ Rate) \times Price\ of\ Water}$$

Through replacing aerators throughout the campus operating at flow rates above 0.5 GPM, with a 0.5 GPM aerator savings may be seen in as little as 4 hours and 12 minutes (254 min) of consistent usage, as portrayed below.

$$\frac{\$2.54}{(2.5GPM - 0.5GPM) \times \$0.005} = 254\ minutes$$

This time will of course vary based on the flow rate of the aerator that is being replaced. A complete listing of time to savings based on current flow rates is seen in table 12.

Table 12: Calculations Made to Determine Return on Investment

Old Flow (GPM)	New Flow(GPM)	Price of water ($/gallon)	Price of New Fixture ($)	Time to Investment Return (min)	Time in hours	Time in Days
Aerator Upgrades						
2.5	0.5	$ 0.005	$ 2.54	254	4.23	0.2
2.2	0.5	$ 0.005	$ 2.54	299	4.98	0.2
1.5	0.5	$ 0.005	$ 2.54	508	8.47	0.4
Shower Upgrades						
2.5	2	$ 0.005	$ 224.45	89,780	1,496.33	62.3
Toilet Upgrades				Flushes to Investment Return		
1.6	1.1	$ 0.005	$ 87.90	35,160		
3.5	1.1	$ 0.005	$ 88.90	7,408		
3.5	1.6	$ 0.005	$ 89.90	9,463		

Another fixture upgrade that was identified was to upgrade the current flushometers to utilize a dual-flush mechanism. This upgrade can be accomplished through the use of Sloan Uppercut Retrofix kit, which has a list price of $87.90. Using equation one, replacing flow rate with volume per flush, we were able to calculate the amount of flushes necessary for the device to pay itself off through the water savings it produced.

We found that it would take 35,160 partial flushes for this dual-flush upgrade to pay itself off. If, however, the toilet upgraded were originally operating at a higher flush volume such as 3.5 GPF, than the newly installed mechanism would take 7,408 partial flushes, or 9463 full flushes to pay itself off (see Table 12 for excel sheet used to produce calculations).

Finally if the showerheads in residential buildings were to be upgraded from a 2.5 to a 2.0 GPM showerhead further savings would be seen on campus. Using equation one again we can calculate the time required for the shower to produce enough water savings to pay for itself. Since the upgraded showerhead only saves ½ a gallon of water per minute it would require a total of 1,496 hours and 20 minutes or more simply, 62.3 days of consistent use to fully repay itself.

As mentioned in an interview with Elizabeth Tomaszewski, WPI is more concerned with being sustainable than with the amount of money it can save. This return on investment shows that eventually these fixtures will pay themselves off, but from a purely financial standpoint this return may be further in the future than WPI would like. Regardless of this WPI should still make the suggested changes (in section 6.0), in keeping with its outlook on sustainability.

5.0 Findings

Introduction

From the analysis of our data we have a better understanding of how WPI consumes water and now know the areas that should be targeted for conservation. The following section describes conclusions that we have been able to make due to various aspects of our project. This section starts with discussing the information gathered in the pre-audit part of the project then goes on to discuss the findings from the actual auditing process. It then goes into the conclusions we were able to come to from analyzing the data from the audit.

Pre-Audit Findings

In the first step of our water audit, we interviewed key members of Facilities to get a better understanding of the water infrastructure and institutional policies on water conservation. From the Facilities System Manager and Acting Sustainability Coordinator, Mrs. Elizabeth Tomaszewski, we obtained information about how WPI works towards creating a more sustainable campus in regard to water. An important discovery was the fact that all future construction and renovations will include fixtures with the lowest available flow rates in order to help reduce water consumption. This is a significant finding because this proves that WPI is ensuring that any additions to the campus will be consuming the least water possible. This is the case even if the higher costs involved with greener technologies are never regained from the savings due to lower consumption. This means WPI doesn't necessarily take cost into account when looking at water conservation methods. WPI as an institution is more interested in becoming a more sustainable entity than trying to save money by cutting corners.

Also we discovered that WPI is encouraging students to become more involved with campus sustainability through student groups. Though the program is recently new, Eco-Reps have been implemented in trying to raise campus-wide awareness about sustainability. Programs like these are important because they help to target the behavioral aspect of sustainability and promote peer to peer learning. WPI can install water efficient fixtures but if they are used improperly they lose their efficiency. Because the program is so new there is yet to be Eco-Reps for every residential building but they do exist in several of the freshman dorms.

From Mrs. Tomaszewski we also discovered that sustainability at the college level is constantly evolving. As the Sustainability Coordinator, Mrs. Tomaszewski attends sustainability conferences in order to learn more about what effective methods are being used elsewhere. In these conferences universities talk about the methods they have used to become more sustainable. They share insight on what worked well and is worth repeating and what was not so successful. Other than the conferences there are annual sustainability surveys that are sent out to try and determine how sustainable universities are. Because these are sent out each year, the bar on what is sustainable is constantly rising. These surveys make it more important that colleges try newer methods to become more sustainable. This in turn strengthens the need for collaboration through the sustainability conferences. With these two methods WPI and schools nationwide are striving for excellence in regards to creating sustainable universities.

From the Chief Engineer of WPI Facilities, Mr. William Grudzinski, we discovered that both the Water Company and WPI Facilities have difficulty locating water meters on campus. To address this issue our team, with the aid of Mr. Grudzinski, physically inspected every building in order to locate the meters. We took pictures, latitude and longitude coordinates, and wrote down detailed directions as we toured the campus locating water meters. With the information gathered we were able to create a map in Photoshop that depicted the relative meter locations. On the back of the map we inserted directions and images to aid the user in locating the meters. Once this map was complete we submitted it to Facilities so that they could utilize it as they saw fit. The final version of this deliverable can be seen in Appendix III.

From Mr. Grudzinski we also obtained the water billing history. Luckily the billing history has been recorded by WPI Facilities since FY 2006 so we had a large set of data to examine. This data did vary from building to building with some entries missing altogether. Since we did have such a long recording period we were still able to make valid conclusions from the data. This was crucial to our project because from it we were able to get a better understanding about how WPI is billed, what types of buildings tend to consume the most, and the general campus consumption trends. From the billing history we discovered that WPI is charged twice per cubic meter of water. The first cost is associated with the potable water that actually comes from the water company. The second is the sewage cost which is based off the quantity of water consumed and is more expensive than the cost of the potable water. The extra cost for the sewage is due to the fact that the water must be treated before it is deemed safe to be returned to the environment.

Consumption trends

Annual water consumption of WPI buildings varies depending on the purpose the building. In recent years residential buildings have seen an increase in water consumption. This could be due to the increase of the student population and variations in behavior. Academic buildings on the other hand have seen significant decreases and general consumption has leveled off since FY 2008. A trend that is visible throughout campus is the drastic consumption drop that took place from FY 2006 to FY 2008. After discussing this trend with Facilities we determined the most likely cause is due to the transition from open water cooling systems to closed systems. Open systems consume large quantities of water because they use cold water from the tap to cool. This water then goes directly down the drain, whereas closed systems do not draw water from the main. By making this switch WPI drastically reduced the amount of water consumed on campus. We believe the consumption decrease is due to the new cooling method because WPI primarily made this change between FY 2006 to FY 2008 and was completed for all buildings by FY 2009. The data we have for campus buildings, shows they all have significant consumption decreases during this period so we believe it to be caused by the cooling change.

Water consumption at WPI follows a general trend of higher consumption during the school year with significantly lower usage during the summer and school breaks. This trend is apparent for almost every building, this is logical due to the fact that water consumption is associated with sanitation, cooking and cleaning, which all depends on the presence of people. With fewer people, all of these activities decrease and so does the consumption connected to them. There are however a few buildings that do not follow this trend; they are Olin Hall and Goddard Hall. These two buildings have significant consumption during the summer and relatively lower consumption during the school year. We know that this consumption is most likely not due to leaks because losses due to leaks will be visible over the entire year and not just the summer months. We did discover some possible reasons for this trend though. The first of which is the fact that both buildings do have research that takes place during the summer. This is more likely a factor for Goddard because significantly more research takes place there than in Olin Hall. Olin, however, has its own possible explanations for the higher consumption during the summer months. The fountain at the center of the WPI campus uses Olin hall as its source for water. The fountain does recycle the majority of its water but there are evaporation and splash losses that need to be replaced. These losses are most likely very minor and still do not explain the extremely high consumption for the summer months. Another possible consumption source could come from the irrigation system. It is unknown if the landscaping around Olin and Goddard get their water from these buildings but it is entirely possible that they do.

From analyzing the consumption data it is apparent that some buildings use much more water than others. The largest consumer of water on campus is Gateway Park. Gateway is primarily used for research which in itself leads to high water consumption. Also Gateway has entities other than WPI that use the building and thus consume water. Unfortunately the data on Gateway has relatively low precision when compared to other buildings on campus. The data has significant rounding, most of which is to the hundred, hundreds of cubic feet. Because of this making an informed analysis of the Gateway data is difficult. We do know that consumption is decreasing but there are no seasonal trends that can be determined to explain why.

Also from the data we know that buildings with dining facilities tend to consume much more water than buildings without. Unfortunately it is very difficult to determine what water is due to dining facilities and what consumption is from sanitation without more extensive metering systems. This was slightly out of the scope of our project so we avoided doing any in depth analysis on buildings of this type.

Analysis Findings

From the analysis of our data we were able to make some important discoveries about consumption trends. One significant fact is temperature and precipitation have no apparent effect on water consumption. To come to this conclusion we looked at the historical monthly temperatures and precipitation measurements in Worcester to see if changes in temperature and precipitation caused consumption to increase or decrease. Since there were no noticeable correlations we know that buildings like Olin and Goddard, which have high summer consumption and possibly irrigation systems, are not directly affected by changes in weather.

Another important finding that we learned from analyzing the buildings is that existing fixtures do not have uniform flow rates. Fixture efficiencies vary from building to building and even within individual buildings themselves. As one would expect newer buildings tend to have greener fixtures and older buildings have more of a variation.

When comparing Daniels Hall and East Hall we discovered LEED certified buildings consume less water than non-LEED buildings. We selected these buildings to make the comparison because they are similar in nature and vary with one being LEED certified, East Hall, and one not, Daniels Hall. These buildings both are residential buildings, have offices on the first floor and contain laundry facilities. From analyzing these buildings it was apparent that East Hall had significantly more efficient fixtures than Daniels. This factor is due to East being required to have efficient fixtures to maintain its LEED certification. If the fixtures in Daniels were replaced with models with lower flow rates it is expected that the total consumption in Daniels would lower making it more comparable to East. Because LEED certification requires more efficient water fixtures, the difference in water consumption is most likely due to one building being LEED certified while the other is not. From this information, one may draw the conclusion that LEED certification results in lower water consumption.

Return on Investment

Through conducting a return on investment analysis on various fixtures that would be recommended to replace existing ones, we were able to identify how much use of each fixture will be required before the new fixture pays for itself in water savings. It was discovered that due to the low cost of replacing aerators on sinks, this upgrade would see the quickest return on investment, while the showerhead we examined costs significantly more, and thus will require significantly more usage to pay for itself. In general the more a fixture costs, the longer it will take to pay itself off. While the amount of water saved does play a role in how fast the fixture will be able to pay itself off, due to the low cost of water, it will have less of an effect on the time to return on investment than the price of the new fixture. From the cost benefit analysis combined with the building analysis, we were able to prioritize not only which fixtures should be upgraded first, but also which buildings should receive these upgrades to maximize water conservation.

6.0 Recommendations

After examining the usage data of the various campus buildings, and conducting an analysis of the fixtures within select buildings, we were able to identify multiple areas that could be made to be more sustainable. We examined the fixtures within a total of five buildings; the buildings examined were Daniels Hall and East Hall to obtain a comparison between non-LEED and LEED certified residential buildings; additionally Olin Hall and Salisbury Labs were examined, as they are two of the older buildings on campus; and finally Gateway was examined as well, because it is the largest water consumer on campus. While many of the following recommendations can most likely be applied to other buildings throughout the WPI campus, due to time constraints we were unable to obtain fixture information for all buildings throughout the campus, and thus cannot make official recommendations for those buildings. The changes that the university would benefit most from can be divided into two categories, fixture upgrades and behavioral changes.

6.1 Fixture Upgrades

As indicated by the sustainability coordinator of WPI, Elizabeth Tomaszewski, WPI always tries to equip its buildings with the most efficient and up to date fixtures during new construction or building renovation. Although the campus is constantly implementing efficient fixtures when possible, there are still buildings throughout the WPI campus, which have not received up to date efficient fixtures in many years, and would therefore benefit from a renovation targeting fixture upgrades specifically.

6.1.1 Faucets

While the labs throughout the campus contain many inefficient faucets and other water fixtures unique to particular labs, such as eyewash stations in chemical labs, it is unlikely that these fixtures will be able to be upgraded to lower-flow fixtures, due to the usage requirements of the labs; however, many of the faucets in the common and more public areas widely very in their flow rates. All faucets on campus utilize an aerator (described in section 2.3.2.1) to limit the flow of water. The aerators throughout the campus range in flow-rates from the most efficient 0.5 gallons per minute (GPM) to the least efficient 2.5 GPM. Due to this large variation in flow-rates throughout the campus, it is our recommendation that all faucets be upgraded to accommodate and utilize a 0.5 GPM aerator. Additionally, it may be beneficial to install faucets which utilize an infrared sensor to turn the water on and off automatically, this would help ensure that faucets do not run longer than necessary.

6.1.2 Toilets and Urinals

As mentioned during an interview with the Sustainability Coordinator of WPI, Elizabeth Tomaszeweski, all toilets on campus utilize a flushometer to control water flow. A diaphragm within the casing of each flushometer decides the volume of water that is used per flush. While many toilets have a recommended flush volume, it is possible that the flushometer uses a diaphragm allowing more or less water than is recommended. Through our research we discovered that the diaphragm's used in the flushometers for toilets (not urinals) throughout the WPI campus are either 1.6 or 3.5 gallons per flush (GPF) (Wagner, 2/14/14). Similar to the toilets, most urinals utilize a flushometer as well; the urinals which do not are the waterless urinals. The diaphragms used within the urinal's flushometers throughout the campus are either 1 or 1.5 GPF (Wagner, 2/14/14).

It is our recommendation that all toilets be standardized to operate at a 1.6 GPF flow rate; furthermore, we recommend that all toilets have the duel flush mechanism installed (further information on this can be found in section 2.3.2.1). In addition to ensuring that all toilets are operating at 1.6 gallons per flush and utilizing a duel flush mechanism, it is also recommended that all urinals are upgraded to at the bare minimum operate on a 1 GPF diaphragm, but preferably they should be upgraded to no-flush urinals.

6.1.3 Showers

Showers cannot only become more efficient through fixture upgrades, but through behavioral changes as well. While it will defiantly be beneficial to implement lower flow showerheads throughout the campus, if this causes an increase in shower time the overall water consumption may rise. Currently the showerheads in place throughout the campus operate at flow- rates between 1.5 and 2.5 GPM. It is recommended that these be upgraded to a showerhead with a flow- rate of 2.0 GPM; this value was selected because Facilities brought to our attention complaints students have made about the low pressure caused by the lower flow-rate showerheads. Additionally, students should be encouraged to minimize their shower time, so as to maximize the potential water savings (refer to section 6.2 for recommendations on how to accomplish this).

6.1.4 Drinking Fountains

When examining drinking fountains through the lens of water sustainability it is seen that attempting to reduce the flow rate of a drinking fountain may compromise the functionality of the fountain itself; however, there are fountains, which contribute more towards sustainability as a whole than others. They do not do this through reducing the water flow, but rather through the inclusion of a bottle filling station. Since this project is focused on reducing the overall consumption of water on the WPI campus, and these fountains will serve to increase consumption of water on the campus while improving overall sustainability, we cannot recommend any water fountain upgrades.

6.1.5 Laundry Facilities

All of the examined washing Machines were Maytag washing machines. The particular model used in on-campus laundry facilities was found to be top tier in terms of water conservation. There is little to be gained through upgrading these machines, rather the campus should focus its efforts on upgrading other fixtures.

6.2 Behavioral Recommendations

Implementing efficient fixtures is only half the battle of becoming sustainable; while the efficient fixtures look great on paper and have the ability to conserve tremendous amounts of water, if they are used improperly their effectiveness will be diminished. For instance if we consider the most extreme example of someone leaving a fixture running while it is not in use, it becomes apparent that for every minute this fixture is left unnecessarily running it is wasting potentially multiple gallons of water. We see this again in the case of a duel flush toilet; should the user choose the larger flush volume when a lower flush volume will work the flush will essentially waste ½ a gallon of water each time this occurs. It is for this reason that measures must be taken not only to ensure the proper use of efficient fixtures, but also to encourage water conservation and sustainable practices amongst the campus population.

The first and perhaps easiest behavioral issue to address would be the proper use of the duel flush mechanism on toilets. The misuse of these mechanisms can be lessened simply by installing an instructional plaque near each toilet, outlining the proper way to use this device. It was shown in a study that the placement of these plaques can reduce misuse by approximately 40% (Arocha, 2013). Similar to these plaques, a sign placed on the mirror near faucets encouraging users to turn off the water during idle time spent at the sink, such as while shaving or brushing teeth, may prove to be beneficial as well.

As discussed earlier (in section 2.4), WPI has recently created an eco-rep program in which volunteer students and staff members learn of ways to live and work more sustainably in a campus environment. This program utilizes peer to peer learning, which has been proven to be a more effective technique in educating others about important issues. The program is still in its early stages, as the university has been unable to provide an eco-rep in each residential building on campus, which is their hope. Since it appears that WPI needs more eco-reps to increase the effectiveness of this program, we recommend that the residential advisors (RA's) receive training in sustainability practices, so they may double as eco-reps. If RA's were to double as eco-reps, each floor would then have at least one eco-rep, and the effectiveness of the program would undoubtedly increase.

"WPI students love numbers" (Tomaszewski, 2/7/14). It is true we are engineers and we do love being able to quantify things. It is for this reason that we suggest the university attempt to provide some form of water usage data to the students. Ideally the students would be able to access a live feed of the water usage for either their floor or their building. This would allow students to quantify the amount of water they use on a daily basis and most likely serve to get more students involved in promoting sustainable behavior. To help encourage the students to be active members in the sustainability movement eco-reps in collaboration with residential services could use this live feed of water usage as a framework to create a sustainability competition.

As an effort to encourage students to live more sustainably it would be advisable to create some sort of sustainability competition in which either each floor competes to see who can be the most sustainable, or each residential building competes; the level of segregation will ultimately depend on the extent of metering that is in place. Currently each building is metered and not each floor, thus it would be less costly to create a competition in which the residential buildings compete rather than each floor of the buildings competing individually. Either way a more extensive metering system will need to be implemented as Morgan hall contains dining facilities and Daniels Hall contains laundry facilities; to ensure a fair competition these consumptions would need to be excluded from the data used to calculate the winner of the competition. Furthermore, since upperclassman reside in suite style dorms that are newer, more efficient, and contain different amenities than the residential buildings provided for first year students, in an effort to keep things as fare as possible the competition should be segregated into different classes of buildings. Specifically, East Hall and Faraday would make a good match up as they contain similar amenities, while the remaining residential buildings, excluding Founders Hall, would all be a reasonable comparison. Founders Hall would most likely be grouped in with East and Faraday; however, it would be at a disadvantage as it is older, less efficient, and contains a dining facility. The Goats Head, Founders' dining facility, would increase the apparent water usage of the building giving all others in the competition an unfair advantage.

6.3 How to Prioritize Fixture Upgrades

Since Residential buildings have some of the most frequently used fixtures on campus, they should be targeted for fixture renovations first. Specifically in Daniels Hall, in addition to upgrading the aerators to ones with flow rates of .5 GPM; the institution should also upgrade the flushometers in place to utilize duel-flush mechanisms. The final upgrade this building should receive is the showerheads suggested in the previous section. Through upgrading the fixtures in this order; aerators, flushometers, and lastly showerheads, the university will see profits sooner as the upgrades would be made in ascending order of the time to pay themselves off. These upgrades may be applied to all other residential buildings that did not receive a fixture analysis, given that they too are in need of these renovations.

Following the upgrades implemented in the residential buildings the academic and research buildings should be next in line to receive upgrades. The upgrades should be focused on floors with high traffic, based on our day to day observations as students who use these buildings consistently, we believe these to be the main floors of buildings. Of the buildings we conducted an analysis on, focus should be given to Salisbury Labs, as it has higher consumption than Olin Hall throughout the year. Specifically the bathrooms below the fourth floor should receive fixture renovations to model the fourth floor bathroom, as it already contains efficient fixtures. Though Olin Hall has relatively low water consumption during the academic year, fixture upgrades would be beneficial, but are less necessary. Because of this the allocation of funding for renovations should be given to higher trafficked buildings. Lastly, Gateway would benefit from upgrading to duel-flush toilets, but already has very efficient fixtures throughout the building and thus should be of the lowest priority. All the upgrades made to these buildings should follow the general order outlined for the residential buildings, i.e. aerators, flushometers, and lastly showerheads.

In general as the flushometers break throughout the campus, thus requiring maintenance, effort should be taken to upgrade these flushometers to include duel-flush mechanisms. Through doing this the campus will be able to slowly upgrade all its toilets to operate with a duel-flush mechanism, which at the very least will ensure all flushes are no more than 1.6 gallons per flush.

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Appendices

Appendix I: Interview of William (Bill) Grudzinski

Transcript of Important Discussion Points

Conducted on November 8th 2013.

Sustainability Team: What we plan to do is to take a water audit of the campus, which looks at the consumption in all the buildings. Determine the volume of water consumed and the sources of consumption. i.e. fixtures

Bill: Are you talking the main campus or everything we own?

Sustainability Team: Just the main campus

Bill: Good, because we have a lot of buildings, but you should also include gateway because it is a major water consumer. The first thing you will need is a list of the water meters and buildings. Are you planning on reading the meters?

Sustainability Team: if the monthly bills contain the consumption data then we won't need to

Bill: so what you would be looking for is the monthly bill, so for instance let's say that you choose 20 buildings, you would be looking for those 20 bills on a monthly basis?

Sustainability Team: Yes, but aren't the bills only from the main meter, not the submeters.

Bill: What submeters? The meters you have for the buildings are the main meters, there are no submeters.

Sustainability Team: so all the buildings are metered individually

Bill: most of them are yes, they all have their own meters with their own bills. Since we have so many water meters, a lot of the time when the water department comes to read them they can't find them, for instance the Higgins labs water meter is outside in the manhole, they always have to come to me to find out where these meters are located, so what I would like is a list of all the buildings and their corresponding meter locations.

Sustainability Team: we're not sure what exactly we will be able to provide in our final report due to the non-disclosure agreements we have signed, but would that be something you think would be ok to show where meters are or…

Bill: I would like to do that, but if you do that does it mean that the meter locations will go public

Sustainability Team: we are not sure how much of it will go public.

Bill: I did this long ago with electric meters and gas meters and they did a project like this and they listed all of them and they took pictures and it was great, there were just certain areas that they had to black out for their public report... If I could get anything out of this I would love to get a list with the meter locations and their corresponding address. I have talked to the water department about this and they said it would really help if there was something that could show them here's the location, here's the building address, and the meter is in this room, maybe with an included picture.

Sustainability Team: yea we can definitely do that, speaking of the water department, who provides the water for WPI.

Bill: DPW

Sustainability Team: do you know off hand how we are billed? Is it a monthly cycle, is it quarterly?

Bill: I believe it is all monthly, the fire system might be metered separately, we'll take a look at it later when we look at the bills.

Sustainability Team: do you know off hand how much WPI pays for its overall water?

Bill: Not a clue I can look at the bills, I know the electric, I know the gas, it seems that water always goes by the wayside.

Sustainability Team: Also in the project we plan to recommend areas that are in need of renovation due to out of date fixtures, so if we can determine when the last time these buildings were renovated that would help our search to determine what areas are most likely not using up to date technologies. Do you have a record of building renovations?

Bill: I may have some, I believe I have some building information where it will say when it was last renovated, type of renovation, square footage...is that what you're looking for?

Sustainability Team: Yea, also do you have a floor plan, it will help locate all bathrooms/pump rooms/ make sure we don't overlook any fixtures that may be in odd places.

Bill: We may just want to download them onto a flash drive for you guys since there are a lot of floor plans...so once we figure out what buildings you want and which floor plans you need we can do that because that would probably be easiest.

Sustainability Team: How often do the water utilities undergo maintenance, because in our research we found that the biggest cause for water loss is leaks…

Bill: We get right on that, **IF** you see it and it's called in we get right on that. We do low flow showerheads, low flow faucets, the students just raised the money for those new water fountains with water bottle filling stations. (IQP: think outside the bottle)

Sustainability Team: Do you think these ways to save water have been effective so far.

Bill: It has definitely helped, but there is still a long way to go...a lot of our peripheral properties still have a lot of outdated fixtures.

Sustainability Team: Do you guys do inspections/ walkthroughs or do you only rely on problems being reported?

Bill: We do a lot of walkthroughs, when we do we are looking for things all the time, like right now we are doing retro commissioning, we are doing gateway and campus center now so we are constantly walking through these buildings.

Sustainability Team: What is a retro commission?

Bill: Basically it's like bringing the building back to original specifications and updating the lighting, updating the utilities and stuff along those lines.

Sustainability Team: What is your official job title that involves you with all these utilities projects?

Bill: I am the chief engineer, I buy the utilities.

Sustainability Team: Are we charged a water and a sewer bill?

Bill: They are both included in the same bill, you'll see when we look at the bills.

Sustainability Team: Are there any conservation programs in place that WPI uses for water?

Bill: I imagine there would be, but that's a question for Liz, Liz works on sustainability, so stuff like that she would have.

Appendix II: Interview of Elizabeth (Liz) Tomaszewski

Transcript of Important Discussion Points

Conducted on February 7th 2014

Liz: we spend about 400,000 dollars on water per year

Liz: our flow rates are lower than the standard requirements, in east hall anyways

IQP team: because our IQP is coming to a close we are going to target a few buildings that we can model around that we have solid data on, because the billing history for some buildings is spotty...olin hall is one of the buildings we are targeting, just to do more of a fixture analysis, Daniels East to kind of get a comparison between lead certified and older residential building, salisbury labs, and Gateway, cuz i believe Gateway is one of the largest water users on campus, and bill specifically asked us to look at that one.

Liz: yea, I think gateway would be real educational for us

IQP team: the main reason for meeting today is to get more of an idea about how wpi looks at sustainability, and how wpi is trying to green in the water in the operations side of the business...bill says that when it comes to utilities water typically falls by the wayside

Liz: I'm not sure i agree with that, that may have been true maybe a decade ago , but as long as our new VP has been here, which i think is 8 years now, he has alot of experience with sustainability and water conservation, and he oversees new construction and building renovations, so whenever possible the department is responsible for looking at water conserving showers and fixtures.

IQP TEAM: so is that something where if, because our goal is to help reduce water consumption, if we make recommendations and point out areas that could have reduced water consumption by switching out to a new fixture, is that something that WPI would take into consideration?

Liz: I'm sure it would, whenever we have had new construction, we have equipped the new buildings with low flow fixtures, and that holds true as well for the building renovations...the renovations for goddard hall and salisbury labs included water conserving fixtures...and you know its really in our best interest, because there may be an upcharge for purchasing the new fixtures that are water conserving, but in the end because they are water conserving we are going to be spending less money on utilities, and its the right thing to do.

IQP TEAM: thats what we hope to actually have in our project, we'll have the return on investment to show how long it will take to pay off the fixtures, and then wpi will actually be seeing how much their saving from these water fixtures, and not to mention the obvious green benefits of them, because even though we are saving money, we're also saving a lot of water.

Liz: thats right, and water is going to be the next most valuable resource, although probably ¾ of the world feels that it is already, but for american citizens i think that we are going to recognize that thats a very valuable commodity, instead of how we treat it now, are you guys aware of the cisterns buried in the quad that help to cool the towers at the sports and rec center

IQP TEAM: oh yea, the rain reclamation?

Liz: yea, and that saves 850,000 gallons of water a year, or so

…

Liz: between 08-09 the water consumption dropped substantially in morgan because we went trayless in the dining hall, and when you go trayless, they didn't have to wash the trays, and that save about 250,000 gallons of water a year.

IQP TEAM: we were just wondering some of the more sort of facilities end of the reasoning why to make wpi more of a sustainable campus, so we wanted to figure out what are the biggest concerns for wpi and the facilities when trying to establish new conservation initiatives?

Liz: well i think the biggest concern we have is simply, trying to do the right thing for the residence, the students, and sustainability, so i think wpi has sort of walked the talk, we feel that we are a sustainable campus, and we want to stay that way, so where we can we will install sustainable fixtures. so you know we're putting our money where our mouth is, i guess i have a little bit of a concern, we have installed water bottle filling stations around campus...when we first installed them in the sports and rec center, in the whole building that was the feature that students were applauding the most, and i agree i think that they are one of the nicest things that we have installed on campus, but there is a good and bad to everything, we are going to be using more water now because of that,

IQP TEAM: yes, but for a disposable water bottle you typically have one amount to fill the bottle and three times that amount to make the actual bottle.

IQP TEAM: so say from our project we found a way to save water, and we wanted to propose a new initiative being part of our project, are there any steps we would need to follow to get initiatives passed?

Liz: i guess it would depend on the kind of initiatives you would recommend, i think what you would expect to happen, would be to continue to install water conserving devices in any new renovation and/or construction that will happen, the trustees had issued a statement in 07 that stated that any new building construction would be LEED certifiable, that doesn't mean it will be certified, it just has to meet LEED certification standards, therefore whatever we built for new construction has to have water conserving appliances installed in it, that being said, i think wpi would do that anyway, because we want to make sure that we are watching the environment and our actions and how the two interface. I'm not quite sure what other actions that you might have in mind for initiatives other than installing appliances that are water conserving.

IQP TEAM: well there are behavioral aspects, its kind of 50/50 you can have great water saving devices, but if they are used improperly, then, there's no real point...dual flush toilets are a good example.

Liz: are you aware of the eco rep program that we have on campus, this is the second year it has been active, we have student eco reps in all of the residential buildings, and i want to say all, but we haven't gotten there quite yet, so the intent in having eco reps in the res buildings in particular is to have peer mentors work toward behavior change, right now we have eco reps that are helping with recyclemania to help the residence in buildings understand that they need to recycle more and try to minimize their waste. they've had initiatives where we've had zero waste week. so people try to understand actually how much waste they create. we are running an energy awareness program in institute hall and 25 trowbridge, where we are actually measuring the amount of electricity that is being consumed on a weekly basis, so we can measure, what our improvement is hopefully and we have done energy load audits in at least 25% of the rooms in those buildings, so i think it would be wise for us to do the next step and look at water consumption. so i understand that for example in morgan and daniels, we may not necessarily know how much water the students are actually using as opposed to the washing machines and dining hall, but we could see a relative increase or decrease on a month to month basis, and that would be education for us, and you know wpi students love numbers, and i think the more numbers we give to students i think the more understanding and awareness we can bring, so i would love to see some initiative like that, water competitions between buildings, that would be fun...there is definitely a behavior change side that we need to look at and thats why we started with the eco rep program because we know that that's an area we need to tackle...studies done by greeneru show that peer to peer education is much better than other forms of education, so you working with your peer students is probably going to be more effective than me telling you how to shower and shave to save water.

IQP TEAM: the biggest problem that we have found is that water costs so little.

Liz: now, but its gonna go crazy

IQP TEAM: water is approximately .5 cents per gallon, so basically with water being so cheap we will have a better chance of getting initiatives passed if we approach our proposal more from an environmental point of view rather than a cost saving one.

Liz: what you're not understanding though, is water as a commodity is going to be increasing at an exponential rate, the cost for it, i own apt buildings in worcester, i remember paying a few hundred dollars a year for water bills, today i'm paying the equivalent of what i pay for property taxes, so i pay $4,000 a year per building instead of a couple hundred, and we expect it to increase, and we've been told the price of water is going to increase. it is a very valuable commodity.

IQP TEAM: so when the sustainability program was still in its early stages and you guys were still working to implement the first sustainable initiatives, did you guys look at any other schools to sort of base what you guys were going to do for wpi off of?

Liz: kind of, we've kind of learned as we've grown in knowing what things to do for sustainability, one of the first things that i started doing when someone asked me to be sustainability coordinator, was to do annual sustainable surveys, like the aashe star survey program and stars is there sustainable tracking analysis and rating system, and sierra clubs coolest schools, and princeton reviews greenest colleges, i do those surveys every year, and they go into real minutia when it comes to what our operations does for sustainability, what kind of energy efficiency equipment we have, what kind of carbon footprint we have, what we use for water conserving devices, what our water consumption is per capita, on and on and on, wpi has always been concerned about sustainability even before it became a popular term, when you look at project based learning, and the wpi plan, its an institution that is concerned about the environment and social welfare anyway, but you know sustainability has been popular maybe over the past 8-10 years and its become a real trend getting involved in the surveys we do has forced us to understand what the standards are and as we do those daunting surveys every year, the standards are being raised, so we get information through that, we also get info from our local community, like i meet with the sustainability coordinators from the other colleges in the city, we get together and we kinda compare notes and talk about different initiatives like water conservation, recycling stuff like that , and people who work in sustainability in general are people who are trying to help each other, so institutions tend to collaborate more with each other rather than compete, to try to do something, because its all really for future generations and the betterment of our environment. so we are learning all the time, we are challenged more every year because the standards are raised and we're kind of competing with ourselves to do better with whatever resources we have available. and those resources in many cases are financial, and in some cases, we have to be very cognasent what we are spending our money on in new construction and building renovations to ensure that we are getting the biggest bang for the buck.

IQP TEAM: are there any buildings that are planned to have renovations?...i'm a physics major so i spend alot of time in olin hall and the bathrooms in olin are not very efficient, so when we're doing the fixture analysis we have found potential areas that could benefit from a fixture upgrade, so if we were to propose areas that need improvement, is that a possible renovation that could happen in the relative future?

Liz: i think that a proposal would certainly be considered, a proposal from a student iqp would certainly be considered a viable proposal.

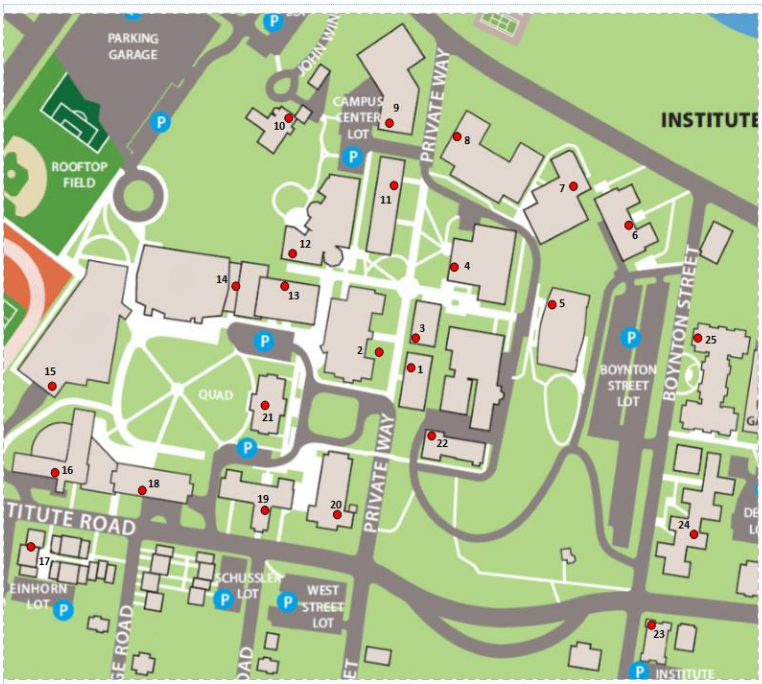
…..

Liz: i can't emphasize enough water is going to be a much more valuable commodity as we move into the future, not just in terms of cost, but in terms of its use as a commodity.

IQP TEAM: is there any additional info that you would like us to provide through our IQP that may help to further sustainable practices at wpi.

Liz: knowledge is power, and we are trying to provide more communication to the entire wpi community on stuff like water consumption, and that info is available to of course iqp students who are doing work on it, but we also publish a sustainability report on an annual basis and that info is in the report, the sustainability plan has just been finalized, and is going to be given to the trustees for their meeting next week, in the sustainability plan, it specifically calls for scrutiny in terms of resources that are consumed by the community. if you look at water consumption by our community it is increasing by a lot, when you look at it per capita however, it remains pretty level. one thing that i would like to see on our campus is using greywater for irrigation rather than potable water...we can't fix what we can't measure so one thing i would include in your report is identifying the source of consumption (largely for irrigation meters.)

Appendix III: Meter Map



Worcester Polytechnic Institute

Building #	Customer #	Building Name	Building Address
1	01-0358-000	Stratton Hall	185 West Street
2	31-0237-000	Higgins Labs	190 West Street
3	01-0371-000	Project Center	191 West Street
4	01-0368-000	Salisbury Labs	201 West Street
5	01-0360-000	Gordon Library	209 West Street
6	01-0362-000	Kaven Hall	125 Salisbury Street
7	12-0293-A00	Fuller Labs	115 Salisbury Street
8	01-0364-000	Atwater Kent	215 West Street
9	01-0365-000	Goddard Hall	210 West Street
10	12-0533-000	Higgens House	1 John Wing Way
11	01-0367-000	Olin Hall	208 West Street
12	01-0374-000	Campus Center	206 West Street
13	01-0372-000	Alumni Gym	200 West Street
14	01-0373-000	Harrington Auditorium	204 West Street
15	12-0297-E00	Rec Center	120 Institute Road
16	12-0300-000	Morgan Hall	90 Institute Road
17	12-0126-000	Stoddard Hall	34 Hackfield
18	12-0298-000	Daniels Hall	82 Institute Road
19	12-0297-000	Riley Hall	74 Institute Road
20	01-0375-A00	Alden Hall	172 West Street
21	12-0297-D00	Bartlett Center	100 Institute Road
22	01-0359-000	Boynton Hall	100 Institute Road
23	01-0526-000	Institute Hall	12 Boynton Street
24	01-0526-A00	Founders Hall	26 Boynton Street
25	01-0531-A00	East Hall	30 Boynton St.
26	14-0165-000	Gateway	31 Garden Street

Produced For: WPI Department of Facilities

Facilities Department Contact: William Grudzinski, Chief Engineer:

Office: (508)-831-6406

Power Plant: (508)-831-5497

Cell: (508)-335-3712

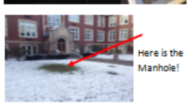
Produced By: Water Sustainability IQP 2013

IQP Team Members: Alexander Wong, Christopher Preucil, Stephen Couitt

Produced on: March 12, 2014

#1 Power House/Stratton Hall Meter:
Location: The meter is inside room 002B. The meter is housed in a cabinet in the left hand corner of room 002B under the window. The cabinet opens from the top.

#2 Higgins Labs Meter:
Location: The meter is outside on the west side of the building. The meter is in a manhole, Identified by its warm temperature.

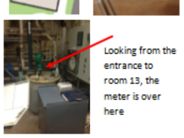


#3 Project Center/ Washburn Shops Meter:
Location: The meter is in a wooden box, in a room, on the first floor in the right hand corner of the building (when facing the main entrance).
Directions: The easiest way to get to the meter is from the outside door (circled) between Stratton Hall and the Project Center

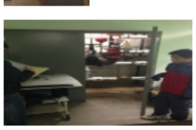
#4 Salisbury Labs Meter:
Location: The meter is in the Humanities and Arts Department Office on the first floor. It is housed under the window in the room directly behind the front desk. Ask the staff in the office for assistance.

#5 Gordon Library Meter:
Location: The meter is on the ground floor. On the floor the meter will be located against the back wall to the right of the elevator.

#6 Kaven Hall Meter:
Location: The meter is in the basement in the right hand corner of room 13.

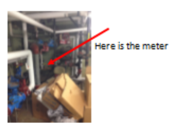


#7 Fuller Labs Meter:
Location: The meter is in the sub-basement in the sprinkler room (Room A17). The meter is behind the door in the image.



#8 Atwater Kent Meter:
Location: The meter is in the basement in the Sprinkler Valve Room/ Standpipe System.

#9 Goddard Hall:
Location: The meter is in room 011, the mechanical room in the basement



#10 Higgens House:
Location: The meter is in the basement (the door will be labeled as a sprinkler valve room, on the door frame).
Directions: In the Basement take a left handed u-turn at the bottom of the stairs, and proceed to the rear right corner of the basement, where the grease trap is located.

#11 Olin Hall:
Location: The meter is on floor 0, in the sprinkler room. The meter will be located against the back wall straight in front of the door.

#12 Campus Center:
Location: The meter is in the mechanical electrical sprinkler (room 122). This room is located near the restrooms on the first floor (across from mail services)

#13 Alumni Gym:
Location: The meter is located in an unmarked room within the laundry room of the gym, the laundry room is located next to the pool balcony spectator entrance (the laundry room is not labeled). Inside the closet within the laundry room proceed down the spiral stairs to the bottom the meter will be to your left in the corner as shown.

#14 Harrington Auditorium:
Location: The meter is located in back right corner of the sprinkler room. The sprinkler room is room 210.
Directions: Either enter Harington from the Rec Center, and walk through the gym to the far end of Harrington to find room 210, or there is a door located next to alumni labeled sprinkler room

#15 Rec Center:
Location: The meter is located on the second floor in the sprinkler valve room (room# 255). Room 255 is located inside room 256.
Directions: Take a left after entering room 256 and you will find room 255 on your left.

#16 Morgan Hall Meter:
Location: The meter is in the basement in the Sprinkler Room (Take the elevator located in the back of the chartwells kitchen.)

#17 Stoddard Hall:

Location: The meter is in the Sprinkler valve room of Stoddard C.

#18 Daniels Hall Meter
Location: The meter is located in the sprinkler room, the sprinkler room is located in room B13.
Directions: ROTC has the key for room B13. The ROTC office is located on the 1st floor of Daniels Hall.

#19 Riley Hall:
Location: The meter is in the sprinkler room, against the wall adjacent to institute road.
Directions: Enter Riley through the "Stage Door" (off of institute rd.), to find the sprinkler room.

#20 Alden Hall:
Location: The meter is in the basement with the sprinkler valve room; however, the meter is not in the sprinkler valve room, it is in the room directly across from the sprinkler valve room.
Directions: The Sprinkler Valve Room can be accesed from a door nearest the West st entrance. If entering through the front entrance take a staircase to your left to get downstairs, and proceed down the hallway of the music department, the West St. entrance will be to your left at the end of the hallway.

#21 Bartlett Center:
Location: The meter is in the sprinkler valve room. The sprinkler valve room is in the basement to the right of the elevator.

#22 Boynton Hall:
Location: The meter is in the basement behind a door with a mirror in the woman's bathroom.

#23 Institute Hall:
Location: The meter is in the basement in room 005. Inside room 005 the meter will be in the back right corner.

#24 Founders Hall:
Location: The meter is in the Sprinkler Room. The sprinkler room for Founders Hall is located in the police station. The sprinkler room will be on your left as you go down the department's hallway.

#25 East Hall:
Location: The meter is in the Sprinkler Valve Control room. The Sprinkler Room is located on the left side of the building next to the church parking lot.

#26 Gateway:
Location: The meter is in room 113. Room 113 is located inside room 118.

Appendix IV: Consumption Data and Statistical Analysis for WPI Buildings

Here is the raw data and the various statistical tests performed. Some patterns in the results and analysis may have been analyzed to see if the pattern was noise or real. The actual values obtained for the statistical test are also found here. Units are hundreds of cubic feet. There is also information on the buildings that were looked at and analyzed holistically, but did not have a fixtures analysis.

A normal t-test is used to do determine if the population differs from a prechosen value. An unpaired t-test compares two data sets and determines if the means are different. A paired t-test uses paired data where every point in one data set corresponds to a specific point in the other set. A paired t-test checks if the differences differ substantially from zero. These t-tests give a t-value. It's equation is a relationship between the standard error and the difference of the means. T-values close to zero indicate no difference detected while a t-value far from zero indicates seeing means that much different are unlikely if the data is in fact equivalent.

A Wilcoxon Matched Pairs Sign Rank Test, or Wilcoxon Sign Rank Test, is similar to the paired t-test. The difference is that the t-test works best with either data in the tens of millions of any distribution or certain types of uni-modal distribution for smaller sets while the Wilcoxon Sign rank test is applicable to any paired data where all differences can be ranked from highest to lowest. The result is a signed rank sum and the farther it is from zero, the less likely a rank sum would be this far or farther from zero if the comparison was between groups of equal means.

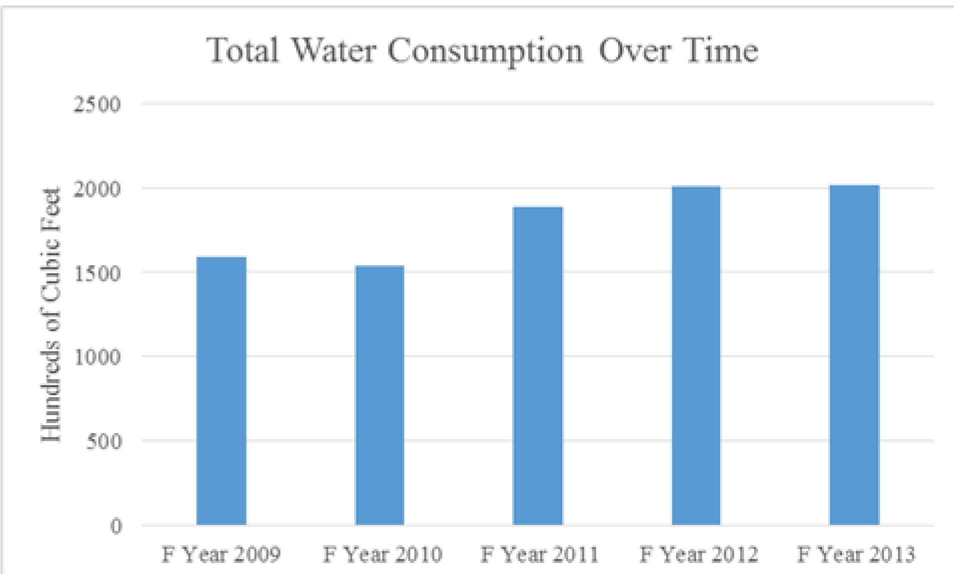
Analysis of variation or ANOVA is an omnibus statistical test. When making multiple comparisons, as opposed to a single comparison of a set to a hypothetical mean or two sets to each other, the risk of assuming a pattern, when there is only randomness, increases. It is not very impressive to make 63 tests with a 95% confidence value and come with 4 significant results. ANOVA allows a screening for these situations and prevents one form seeing false patterns merely because one is making lots of comparisons. The test statistic of an ANOVA is an F-value. If this is higher, there is a higher probability of a true pattern

East Hall
Building: East Hall
Building Class: Residential
Construction Year: 2008
30 Boynton Street
Customer ID: 01-0531-A00

Table 5. East Hall Consumption (100 ft^3)

Fiscal Year	**2009**	**2010**	**2011**	**2012**	**2013**	**AVG**
July	NA	10	10	10	30	16
August	NA	10	20	30	50	31
September	610	190	200	210	230	264.546

October	180	200	280	260	250	268.182
November	220	170	210	240	230	236.364
December	100	180	200	230	220	219.091
January	NA	40	130	80	70	88
February	140	190	200	260	300	237.273
March	180	190	170	200	220	194.546
April	NA	150	250	280	350	279
May	150	170	200	180	6	162.727
June	10	40	20	30	60	34.546
Total	1590	1540	1890	2010	2016	2000
AVG	198.75	128.333	157.5	167.5	168	166.553



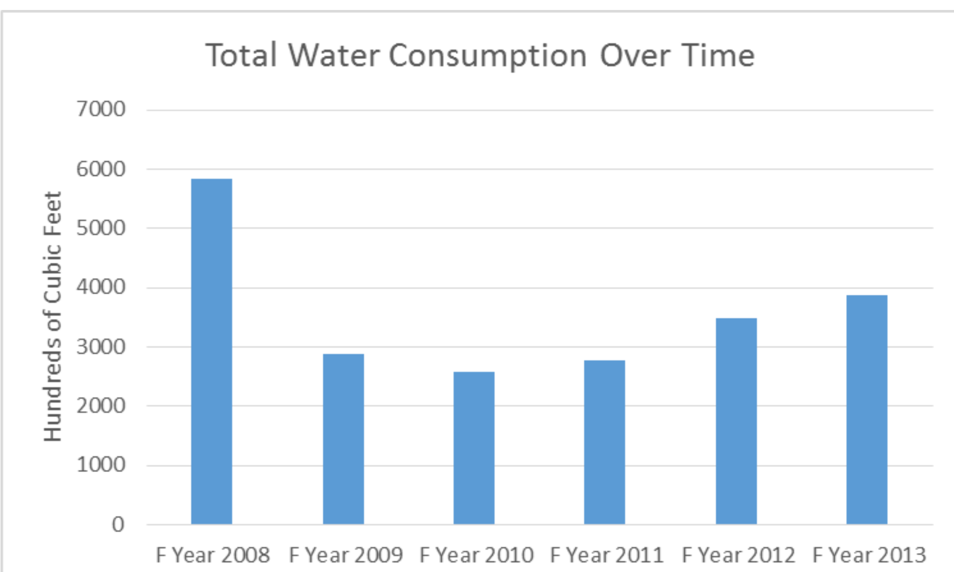
A t-test was conducted on our data to determine how much more water East Hall used in fiscal year 2013 than in previous years. The p-value threshold was chosen to be .00269. This results in an interval of .712 to 51.862 centered around 26.287. This indicates that during fiscal year 2013 East Hall consumed approximately 26.287 additional units on a monthly basis; furthermore, since this test is bounded by .712 to 51.862 with a 99.731% confidence, it can be said with great confidence a typical month in fiscal year 2013 consumed more water than the previous years. Since the unit on the table is hundreds of cubic feet of water, this means fiscal year 2013 had a monthly consumption of 2628.7 cubic feet of water more than past consumption patterns, bounded by 71.2 to 5186.2 cubic feet of water.

Daniels Hall
Building: Daniels Hall
Building Class: Residential
Construction Year: 1963
Customer ID: 12-098-000

Table 6. Daniels Hall Consumption (100 ft^3)

Fiscal Year	**2006**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**AVG**
July	150	256	152	35	46	118	305	154.316
August	NA	326	354	143	196	325	321	279.083
September	NA	958	400	379	399	424	325	431.75
October	323	688	394	323	373	436	330	392.75
November	NA	436	281	276	284	353	335	325.75
December	300	616	150	277	233	389	340	324.438
January	NA	184	269	39	135	94	350	185.75
February	NA	664	217	292	238	369	170	292
March	NA	408	300	263	207	282	350	290.667
April	NA	542	NA	231	304	289	350	327.454
May	NA	556	268	296	257	130	350	277.583
June	NA	200	91	39	113	290	350	215.75
Total	773	5834	2876	2593	2785	3499	3876	4782
AVG	257.667	486.167	261.455	216.083	232.083	291.583	323	398.495

Fiscal year 2007 was deleted since it had no data. Incorporating the previous year is necessary because it aids in lowering the uncertainty of the mean water consumption of July, October, and December. Data should never be thrown out even if it is an outlier unless there is compelling reason to decide it is inaccurate.



In determining if there was a statistically significant difference in the years consumptions at all, a paired analysis of variation was performed on the most recent years with a p-value threshold of .000333. The mean squares between the years was 32,697 and the residual mean squares was 5,500. The p-value is below .0001. Since global rejection of the null hypothesis, that all the years were equal is rejected, an individual analysis can begin.

Looking at water consumption, a Wilcoxon matched paired signed rank test was performed on some years. The p-value chosen for cutoff was .05 for all of them. From fiscal year 2010 to 2011, the rank sum was 31. This results in a p-value of .0031, so water consumption in fiscal year 2011 was significantly higher than it was the previous year. Comparing the next pair, the rank sum was 54. The p-value ends up being less than .0001, so water consumption in fiscal year 2012 was significantly higher than it was the previous year. The most recent years have a signed rank sum of 21. This results in a p-value of .0263, so water consumption in fiscal year 2013 was significantly higher than it was in the previous year.

Morgan Hall
Building: Morgan Hall
Building Class: Residential
Construction Year: 1953
Customer ID: 12-0300-000

Table 7. Morgan Hall Consumption (100s of cubic feet)

Fiscal Year	**2009**	**2010**	**2011**	**2012**	**2013**	**AVG**
July	580	40	10	70	10	80.909
August	640	240	260	210	90	232.727
September	640	930	740	610	470	639.091
October	394	820	1060	760	490	740.364
November	680	780	760	610	470	645.545
December	350	850	610	590	380	540
January	NA	9	350	160	120	189.9
February	470	760	610	610	510	583.637
March	650	730	530	460	370	496.364
April	NA	660	750	660	640	681
May	490	780	530	287	150	379.182
June	30	30	20	10	10	16.364
Total	4924	6629	6230	5037	3710	5224
AVG	492.4	552.4167	519.166	419.75	309.1667	435.37

This table shows how much water Morgan Hall consumed on a monthly basis in hundreds of cubic feet.

The water consumption is higher than other dorms. This is likely due to the presence of the dining hall, which will be discussed later. Unlike the other dorms, Morgan Hall seems to have been trending downward for the past three years. In August of fiscal year 2009 and 2012, there is an abnormally high water usage.

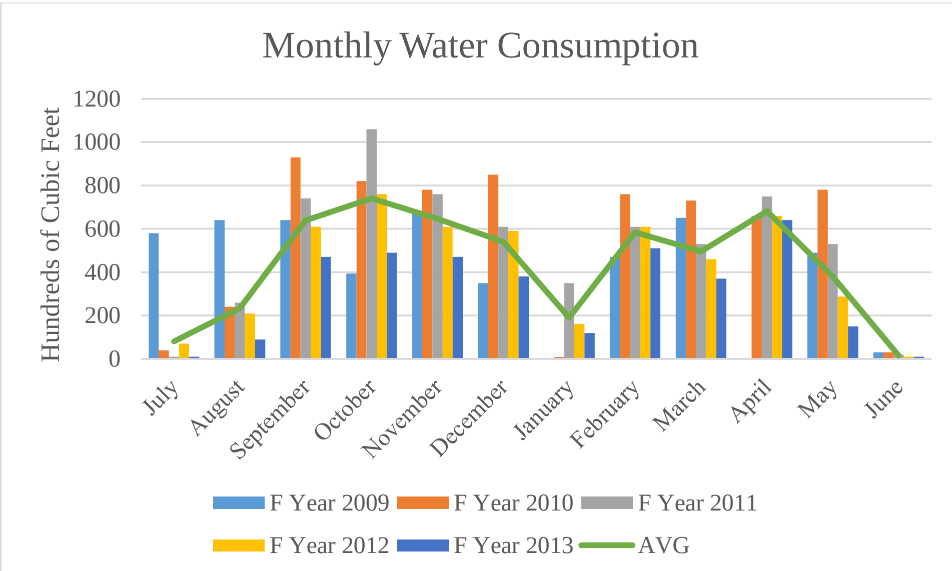


Figure ?. Morgan Hall Consumption Data Visualized

The same seasonal trend of the water consumption being lower when there are breaks is seen again, but this is much more pronounced than any of the previously observed residence halls. This is probably due to the fact that there is a dining hall there, and this exaggerates the trend. During break the hall is either shut down or doesn't have to use many dishes. Despite the fact that the dining hall is in operation during E-term, Morgan Hall doesn't use much water in June, this is most likely attributed to the lowered occupancy of the building after the completion of D-term.

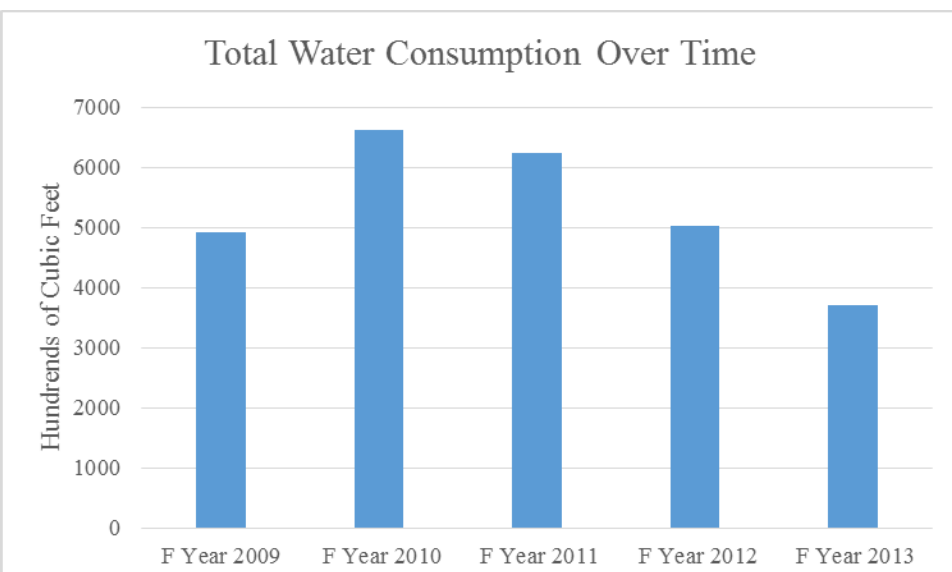


Figure ?. Morgan Hall Total Consumption Over Time

While there appears to be a variation of water consumption over time, in fact most of the years have mean monthly consumption where differences cannot be detected. The exception is fiscal year 2013, which has noticeably lower water consumption, as proven by the statistical tests that will be discussed later.

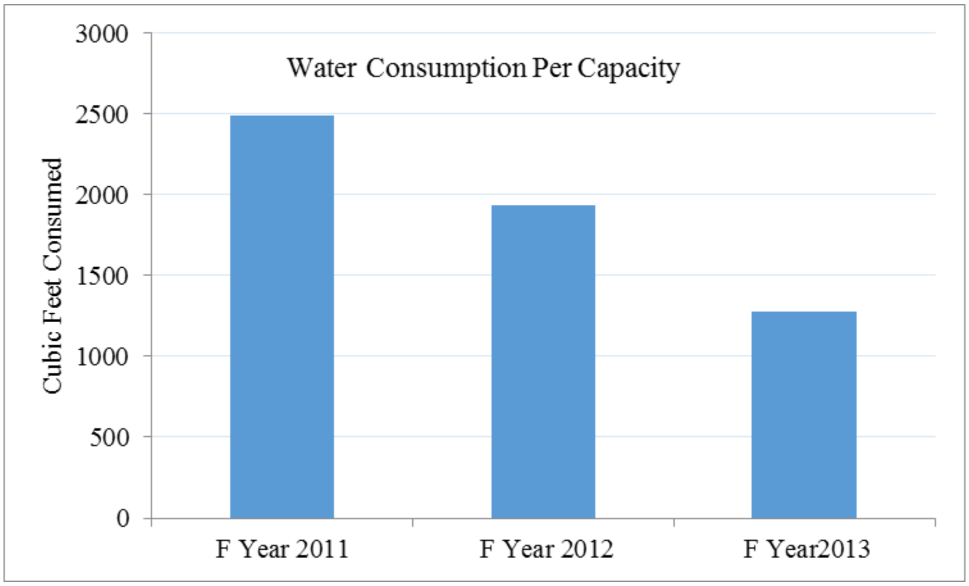


Figure ?. Morgan Hall's water consumption divided by its capacity for the recent years

Like most resident halls, Morgan Hall's water usage fluctuates throughout the year. Like most main campus buildings, the D-term water usage tends to be high. Also, there is little water consumption in the summer, during the time students are gone and building occupancy is lowered. Unlike most buildings, Morgan's September consumption is consistently higher than December, March, and May compared to an average month.

Morgan Hall contains a dining hall, but it lacks laundry services; this is because it is connected to Daniels Hall, which has a laundry room. The dining hall appears to consume more water than the laundry machines of other dorms, making Morgan a large water user. Starting fiscal year 2013, the dining hall was renovated. It should also be noted that while there have been small decreases in total water consumption in some years, for this dorm the biggest decrease started in fiscal year 2013, the one when the dining facility was renovated. It is likely that the new dining facility caused the water consumption at this building to drop. This is perhaps due to upgraded equipment and fixtures. Morgan Hall consumed between 76.345 and 150.580 less units per month in fiscal year 2013 than the preceding years. This year is the only one that is significantly different from the rest, in other words the other years are effectively equivalent to each other.

Paired analysis shows at the 95% confidence interval, all the years have about the same water consumption with the exception of fiscal year 2013. Compared to the previous year, fiscal year 2013 consumes less water. The paired t-test gives a p-value of less than .0001. Setting up a 99.731 confidence interval, it can be said that Morgan Hall consumed between 76.345 and

150.580 less units per month in fiscal year 2013 than the preceding years. Again, the units are hundreds of cubic feet of water.

Interbuilding analysis

To test if LEED makes a difference in water consumption, a paired t-test was performed between Daniels Hall, an older residence hall, against East Hall, a spiffy new LEED certified one. The t-value was above 3 and the p-value was below .0001. The conclusion is the East Hall building consistently consumes less water than Daniels Hall on a monthly basis. This is not a surprise because East Hall is expected to be more sustainable, as is the goal of LEED certified buildings. The real question is how much more sustainable its water consumption is. On a 99.731% confidence interval, Daniels Hall consumes between 51.958 and 160.432 units per month more than East hall. Again, the data from the water bills are hundreds of cubic feet of water. It is apparent LEED buildings are indeed better.

Atwater Kent
Building: Atwater Kent
Building Class: Academic
Construction Year: 1907
Customer ID: 01-0364-000

Table 8. Atwater Kent Consumption (100s of Cubic Feet)

Fiscal Year	**2006**	**2007**	**2008**	**2009**	**2010**
July	48	48	54	40	13
August	60	72	62	44	22
September	88	62	68	28	34
October	130	120	74	39	38
November	228	178	60	53	33
December	154	?	74	44	36
January	172	94	54	20	12
February	200	66	78	35	37
March	182	82	58	33	41
April	164	?	60	39	34
May	144	?	74	33	38
June	54	60	28	29	17
Total	1624	782	744	437	355
AVG	135.333	65.167	62	36.417	29.5833

Fiscal Year	**2011**	**2012**	**2013**	**2014**	**AVG**
July	17	16	15	14	20.15
August	19	220	20	18	75.55
September	32	34	36	35	37.85

October	43	47	54		56.438
November	36	39	43		60.25
December	36	47	44		51.25
January	23	13	14		31.125
February	31	47	46		52.125
March	31	39	38		48.125
April	51	51	65		61.5
May	38	36	21		41.667
June	15	17	16		22
Total	372	606	412		544
AVG	31	50.5	34.333	18	42.163

Unlike most of the other buildings, it is difficult to see any of the trends from the table alone. The only thing that is immediately obvious is that the building has been consuming less water over the years. Also note that fiscal year 2012 seemed to consume a large amount of water for no adequate reason.

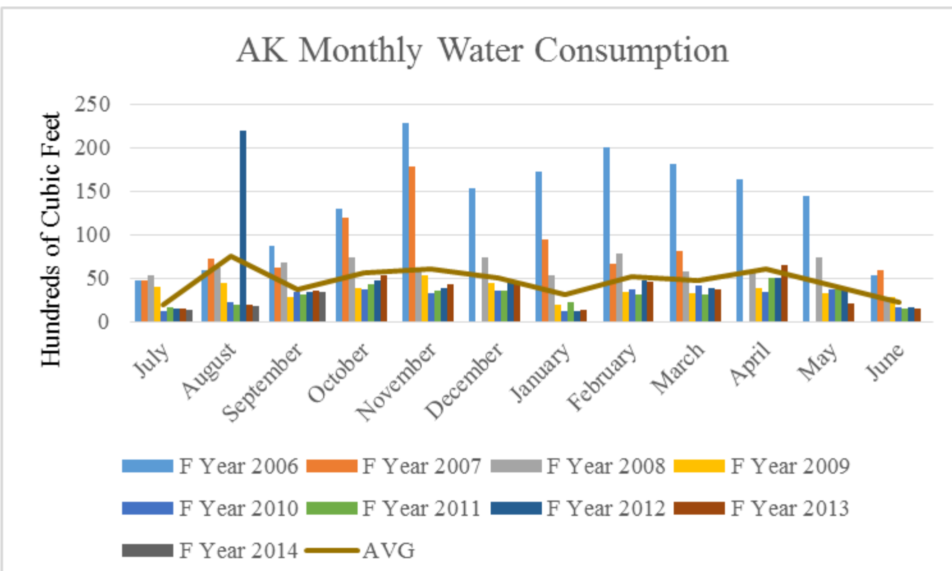


Figure 10. Atwater Kent Data Visualized

It can be seen that with the exception of fiscal year 2006, most of the years seem to have minimal variation within the year. The AVG line that goes across and is nearly flat confirms this. With so many years, it is a bit difficult to see all the trends well.

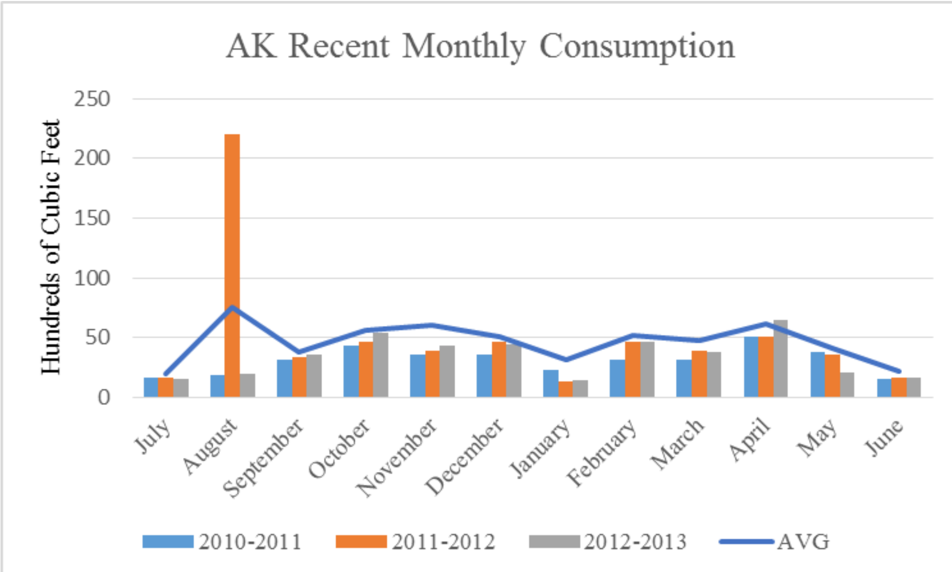


Figure 11. Atwater Kent Recent

Figure 11 is effectively a zoomed in graph of the previous figure with emphasis of the recent consumption. With the exception of the random spike for one month in fiscal year 2012, the water usage doesn’t change too much in a given year.

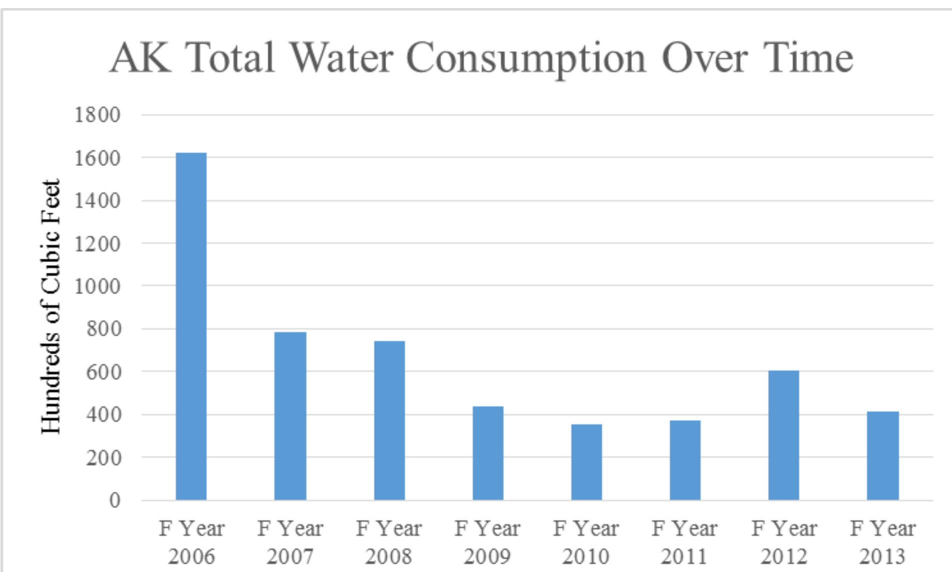


Figure 12. Atwater Kent Total Consumption Over Time

There is an apparent decline in water consumption over the years, with the exception of the small spike in fiscal year 2012.

Atwater Kent has lots of ECE classes. It has a somewhat high traffic, but qualitative observations of the bathrooms suggest that a set of ground floor bathrooms have a moderate amount of traffic and the other bathrooms are rarely used.

Atwater Kent laboratories had a marked drop in water consumption since fiscal year 2006. In August 2011, which was in fiscal year 2012, the building used triple the August norm for this building. It should be noted that this building's water consumption information appears to be more accurate than the resident halls.

Like most buildings, there is the general trend that less water is used during breaks. The trend is very weak in this building. The seasonal trends appear to be weakening as the building consumes less water over time. Statistical tests showed that fiscal year 2006 was indeed a high annual consumption and the apparent pattern is true.

After some more tests, a few more specific conclusions were reached. Early recording years used between 44.731 and 92.079 units of water monthly than fiscal year 2011. Early recording years used between 25.659 and 73.007 units of water monthly than fiscal year 2012. Early recording years used between 41.236 and 88.584 units of water monthly than fiscal year 2013. Note that none of these intervals cover zero, consistent with the rejection of the null hypothesis. Note that each unit is one hundred cubic feet of water.

As for within the recent years, there is weaker evidence of difference. A month in fiscal year 2012 uses significantly more units of water than the previous fiscal year, but the other years cannot have their means separated. Again each unit is 100 cubic feet of water.

The takeaway message from these tests is that the early years consumed a detectable amount of more water than fiscal years 2011, 2012, and 2013 and that fiscal year 2012 consumed more water than fiscal year 2011.

A quick comparison was made to asses if the high consumption of fiscal year 2006 was a statistical fluke or not. Using the Wilcoxon Rank Sum test, it is determined that the sum of signed ranks is -6238. The p-value for this test is less than .0001. 2006 did indeed use much more water than typical years.

To test if the consumption of water changes over time, a paired ANOVA was run. One group had averages excluding the most recent while the other groups were fiscal years 2011, 2012, and 2013. For the analysis these groups will be called early recoding years, 2011, 2012, and 2013 respectively. The critical p-value was set to be .00269 or a 99.731% confidence level. The squared sum between the years was 331473. The mean square between the years was 110491. The mean square of the residual or error was 1395. The F value was 79.204, for a p-value less than .0001, much less than the threshold.

Since the global null hypothesis can be rejected, one can look at the groups. On average, the early recording years used on average more per month by 68.405, 49.333, and 64.910 units than fiscal years 2011, 2012, and 2013 respectively. The comparisons' q-values are 19.296, 13.916, and 18.310 respectively. This is deemed statistically significant since the p-value for all three of these comparisons by Tukey's Honest Significant Difference test is less than .0001, much less than the threshold.

Comparing fiscal year 2011 and 2012 yields a q-value of 5.380. Comparing fiscal year 2011 and 2013 yields a q-value less than 1. Comparing fiscal year 2012 and 2013 yields a q-value of 4.394.

Goddard Hall

Building: Goddard Hall
Building Class: Academic
Construction Year: 1965
Customer ID: 01-0365-000

Table 10. Goddard Hall (100s of Cubic Feet)

Fiscal Year	**2006**	**2007**	**2008**	**2009**	**2010**
July	320	220	140	120	50
August	400	280	180	60	150
September	56	240	240	40	150
October	280	340	100	80	60
November	320	280	160	90	100
December	380	?	140	50	90
January	340	340	60	40	40
February	380	200	140	100	80
March	320	280	120	60	70
April	220	?	240	120	50
May	240	?	180	90	70
June	200	240	80	170	70
Total	3456	2420	1780	1020	980
AVG	288	201.667	148.333	85	81.667

Fiscal Year	**2011**	**2012**	**2013**	**2014**	**AVG**
July	260	110	170	260	181.25
August	240	630	230	210	233.5
September	250	160	140	170	173.8
October	150	90	80		123
November	130	30	70		105
December	70	40	50		87.692
January	70	30	10		69
February	80	50	60		92.5
March	60	50	60		85
April	70	80	60		96.923
May	70	60	40		83.462
June	70	90	120		108
Total	1520	1000	1090		1385
AVG	126.667	83.333	90.833		115.442

Note that in any given year, August has higher water consumption than the average water consumed in that year.

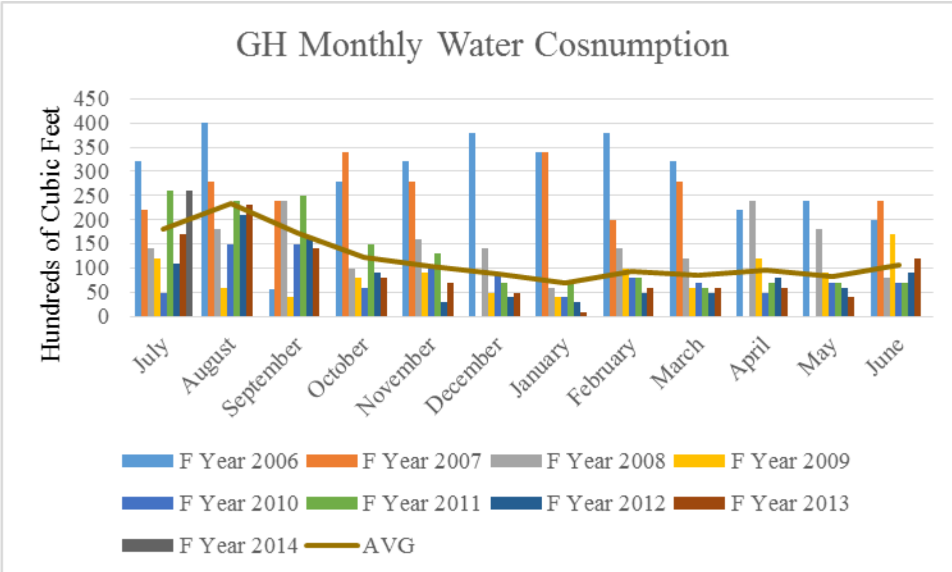


Figure 13. Goddard Hall Data Visualized

Note that the high usage months are in A and E term and August.

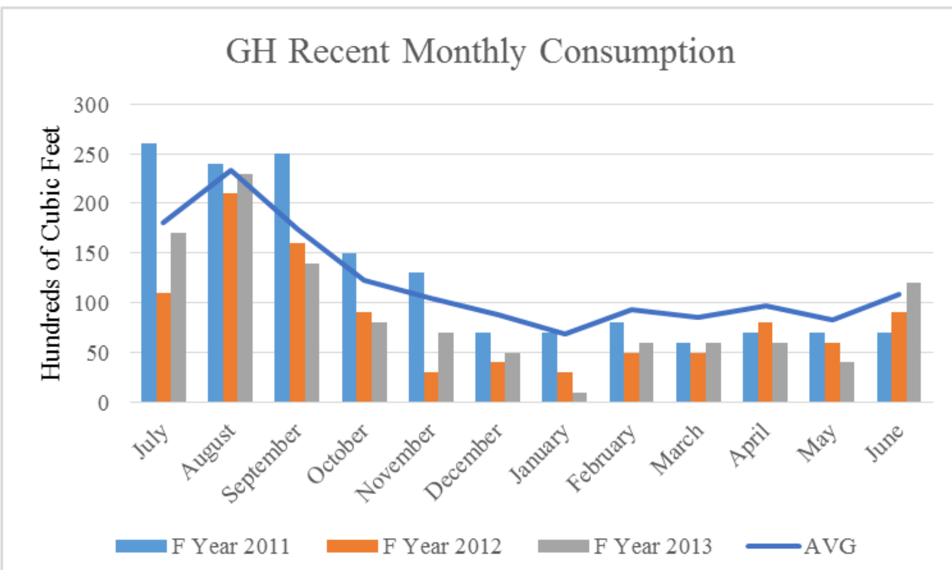


Figure 14. Goddard Hall Recent

For most of the months, recent water consumption has declined for the most recent three complete fiscal years.

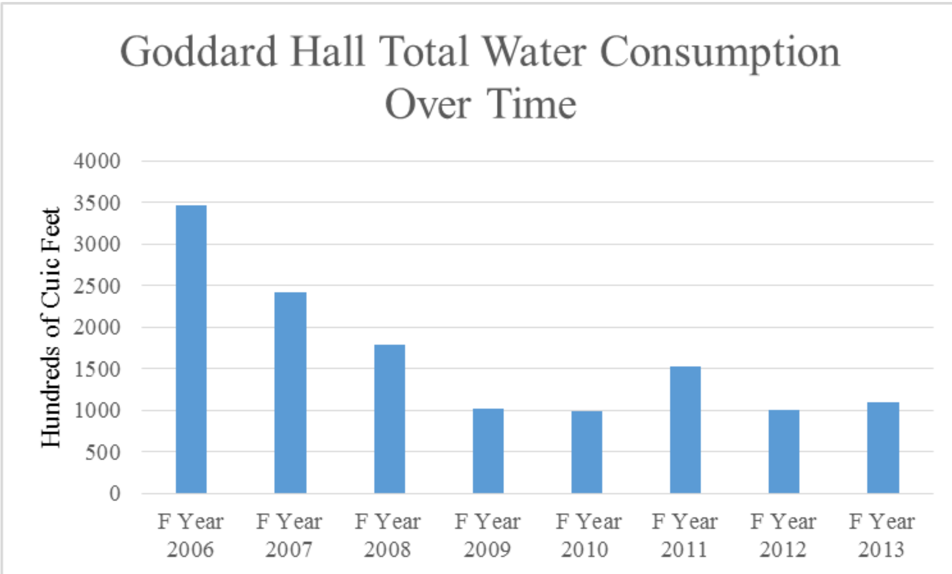


Figure 15. Goddard Hall Total Water Consumption Over Time

It is really obvious that water consumption went down over time in this building. More recently, the water consumption leveled off. Despite the large fall off, the building still uses more than 1000 units annually.

Like most buildings, the overall water consumption fell over the years. Unlike other buildings, water consumption in Goddard Hall appears to be largest during E and A terms. This is probably due to the fact that it is a lab. Most of the water consumption is unlikely to be sinks and toilets but washing lab equipment, otherwise it would be dependent on the traffic and have lower consumption during the break months like most of the other buildings. In effect usage is determined by whenever someone wants to do a lab here, for class an MQP, or just work for a professor. The building usage trends will likely be determined by habits of biology and biochemistry professors. The most recent years have been of lower consumption in general, however this might be part of the general trend that most of the buildings do not seem to have very accurate data until fiscal year 2011.

The statistical tests show that the variation between years was real. Since the global null hypothesis is rejected, analysis can be done on the individual groups. Like Atwater Kent, Goddard Hall used more water in the early recording years than the recent ones. On average, the early recording years used on average more per month by 53.089, 62.384, and 88.571 units than fiscal years 2011, 2012, and 2013 respectively. Tests show that boundaries of these differences. The early recording year used between 10.22 and 95.958 units per month than 2011. Comparing with 2012 results in the old years using 19.515 and 105.253 per month. The comparison with fiscal year 2013 has a difference of 45.702 and 131.44 units monthly. In contrast, there is no detectable difference between fiscal year 2011 and onward.

Once again, water usage in the later years is smaller. This might be due to the fact that a lot of biology experiments moved into Gateway Park. Goddard uses a lot more water than other academic buildings. This is likely to be due to the labs and much of the water is probably washing equipment, not flushing toilets or washing hands like a lot of academic buildings.

To test if the consumption of water changes over time, a paired ANOVA was run. One group had averages excluding the most recent while the other groups were fiscal years 2011, 2012, and 2013. For the analysis these groups will be called early recoding years, 2011, 2012, and 2013 respectively. The critical p-value was set to be .00269 or a 99.731% confidence level. The squared sum between the years was 464415. The mean square between the time periods was 1054805. The mean square of the residuals or error is 8201. The F value of the test was 18.88. The p-value was less than .0001, well below the threshold.

Since the global null hypothesis is rejected, analysis can be done on the individual groups. Like Atwater Kent, Goddard Hall used more water in the early recording years than the recent ones. On average, the early recording years used on average more per month by 53.089, 62.384, and 88.571 units than fiscal years 2011, 2012, and 2013 respectively. The comparisons' q-values are 6.204, 7.290, and 10.351 respectively. This is deemed statistically significant since the p-value for all three of these comparisons by Tukey's Honest Significant Difference test is less than .0001, much less than the threshold. Again the units are in hundreds of cubic feet of water.

With the 99.731% threshold, confidence intervals can be determined. The early recording year used between 10.22 and 95.958 units per month than 2011. Comparing with 2012 results in the old years using 19.515 and 105.253 per month. The comparison with the most recent fiscal year has a difference of 45.702 and 131.44 units monthly.

The years have less q values. 2012 and 2013 have a q value of 3.060. Comparing 2011 to 2012 and 2013 have q values of 1.086 and 4.147 respectively. All these q values are too low to be statistically significant.

Salisbury Labs
Building: Salisbury Labs
Building Class: Academic
Construction Year: 1913
Customer ID: 01-0368-000

Table 10. Salisbury Labs Water Consumption (100s of Cubic Feet)

Fiscal Year	**Year 2006**	**Year 2007**	**Year 2008**	**Year 2009**	**Year 2010**
July	160	180	40	80	10
August	100	160	40	60	20
September	160	160	80	20	40
October	360	260	100	50	30
November	340	180	120	70	30
December	220	?	80	60	30
January	280	220	60	30	10
February	340	180	80	30	30
March	220	240	80	30	30
April	360	?	120	40	40
May	400	?	80	30	50
June	340	100	40	20	20
Total	3280	1680	920	520	340
AVG	273.333	140	76.667	43.333	28.333

Fiscal Year	F Year 2011	F Year 2012	F Year 2013	F Year 2014	AVG
July	20	10	20	10	42

August	20	381	20	30	96.333
September	40	40	40	40	57.333
October	50	50	50		89.286
November	30	30	40		74.286
December	30	50	40		57.692
January	20	10	10		51.429
February	40	40	40		72.857
March	30	30	40		64.286
April	40	50	60		77.692
May	40	30	10		61.538
June	10	10	30		47.858
Total	370	731	400		
AVG	30.833	60.917	33.333	26.667	61.766

Note August of fiscal year 2012 has huge water consumption with no adequately explained reason. Salisbury Labs has had a major decline in water usage over the years. Also note a high usage in general, even the lower recent ones.

Once again, a paired ANOVA was run on the data. One group had averages excluding the most recent while the other groups were fiscal years 2011, 2012, and 2013. For the analysis these groups will be called early recoding years, 2011, 2012, and 2013 respectively. The critical p-value was set to be .00269 or a 99.731% confidence level. The squared sum between the years was 1570182. The mean square between the time periods was 523394. The mean square of the residuals or error is 5949. The F value of the test was 87.986. The p-value was less than .0001, well below the threshold.

Since the global null hypothesis is rejected, analysis can be done on the individual groups. The pattern of less water usage in the recent years is seen again. On average, the early recording years used on average more per month by 141.667, 111.992, and 139.401 units than fiscal years 2011, 2012, and 2013 respectively. The comparisons' q-values are 19.868, 15.706, and 19.550 respectively. This is deemed statistically significant since the p-value for all three of these comparisons by Tukey's Honest Significant Difference test is less than .0001, much less than the threshold. Again the units are in hundreds of cubic feet of water.

The next step is determining how much more water was consumed monthly. Constructing the 99.731% confidence interval, the early recoding years consumed 106.12 to 177.214 more units of water monthly more than fiscal year 2011. Comparing the early recoding years to the next year yields 76.445 and 147.539. Third, it can be concluded an average month in the early recoding years compared to an average month of 2013 used 103.854 and 174.948 more units of water.

Once again, the last three years do not significantly differ. For q values to determine if means are different, the results show little difference. For fiscal year 2011 and 2012, the q value is 4.162. For fiscal year 2011 and 2013, the q value is 0.318. For fiscal year 2012 and 2013, the q value is 3.844. In effect, the three most recent complete fiscal years did not consume a detectably different amount of water.

Higgins Labs
Building: Higgins Labs
Building Class: Academic
Construction Year: 1913
Customer ID: 31-0237-000

Table 11. Higgins Labs Consumption (100s of cubic feet)

Fiscal Year	**2006**	**2007**	**2008**	**2009**	**2010**	**All AVG**
July						18.25
August	100			50		27.75
September		140	120		75	59.875
October						30
November				110		50
December	220	300	180		75	73.438
January						14.333
February				70		45
March	120		140		70	47.5
April						33.333
May	180	34				48.75
June			140	70	80	39.667
Total	620	474	580	300	300	
AVG	51.667	62.25	48.333	25	25	31.488

Fiscal Year	**2011**	**2012**	**2013**	**2014**	**AVG F Year 2011-2014**
July	3	20	20	30	18.25
August	30	1	20	30	20.25
September	87	30	30	35	45.5
October	30	40	20		30
November	30	30	30		30
December	40	30	30		33.333
January	1	10	30		13.667
February	40	40	30		36.667
March	30	20	30		26.667
April	30	40	30		33.333
May	30	28	30		29.333
June	20	12	30		20.667
Total	371	301	330		
AVG	30.917	25.083	27.5	31.667	28.792

Until Fiscal Year 2011, like most of the buildings the data has limited accuracy. For Higgins Labs, this seems particularly true since there are several blanks. As a result, there is a total average for all the years as well as one that only takes into consideration the recent years.

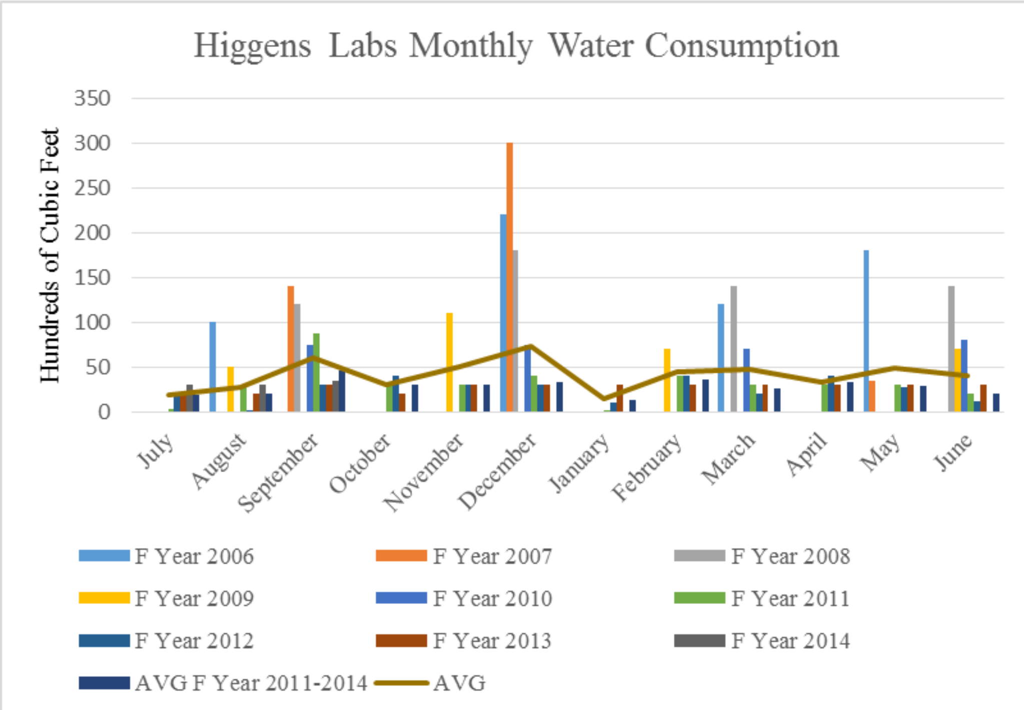


Figure 19. Higgins Labs Monthly Water Consumption

Note that December appears to have egregious water consumption for fiscal years 2006, 2007, and 2008.

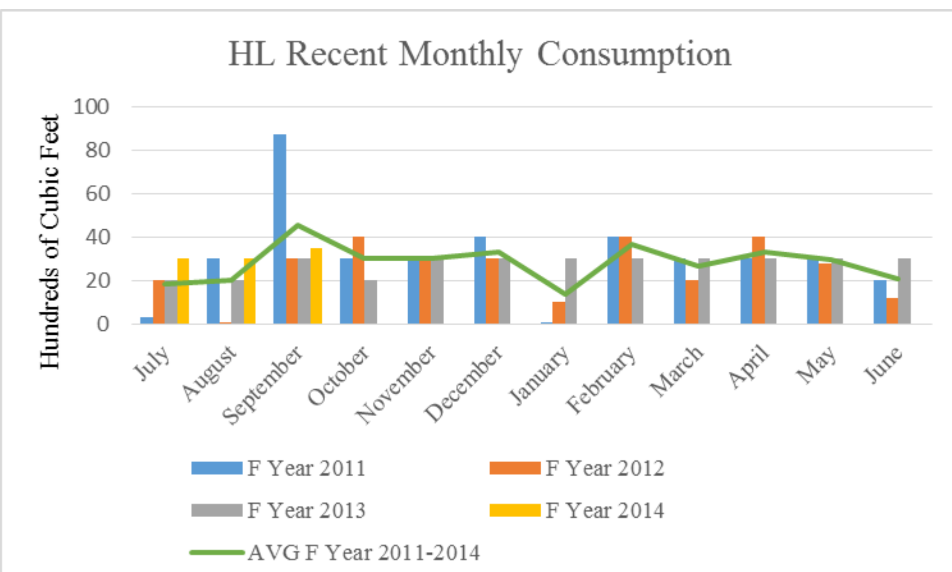


Figure 20. Higgins Labs Recent

Since previous records are very spotty, zooming into the more recent years is very useful. Also, the AVG line used here only takes into account the more recent years. The December anomaly disappears in recent years.

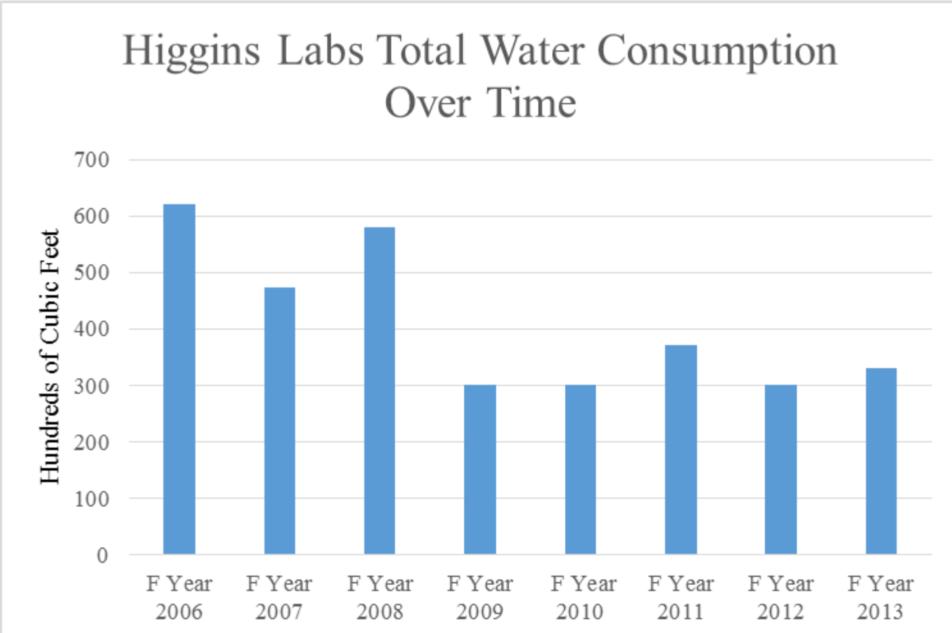


Figure 21. Higgins Labs Total Water Consumption Over Time

Higgins Labs had a total water consumption fall over time. Note that in figure 21, the scale only goes up to 700 units, so the drop is much more modest.

Like most of the other academic buildings fiscal year 2006 used the most water in years with available data. The most recent years have been of lower consumption in general, however this might be part of the general trend that most of the buildings do not seem to have very accurate data until fiscal year 2011. This is particularly true for this building which seems to have spotty data before fiscal year 2011. Because of this, two averages are given a look at, one that incorporates all the years and one that looks at the three most recent years.

Once again the early recoding years is used to compare with the three most recent years. The data is not complete and gaps are present in some months. This causes a problem for paired analysis since every data set must be matched in every group. One possibility is to simply throw out July, October, and April data, but this would induce bias. The chosen solution is to use the monthly average of the early years to fill in the gaps. A statistical test shows that the years are indeed different. Since there is a detectable difference in the overall data, a closer look can be given to the individual years.

Over time again, the years in the available data proved to be detectably different from each other. In addition, the water usage had to be estimated for earlier years. Statistical tests show that the early years did indeed consume more water than the recent ones. Each difference has a lower and upper limit and an average. The difference is likely to be the average, but it can be said with high confidence it is not below the lower bound or above the upper one. The early years used from of 67.233 to 98.003 more units per month than fiscal year 2011, with an average of 82.618. The early years used 71.893 to 105.013 more water per month than fiscal year 2012 with an average of 88.453. Third, the early years used 71.983 and 105.013 more water per month than fiscal year 2013 with an average of 86.032.

Higgins Labs consumed less water monthly as time passed like the other buildings. Unlike the other buildings where this was simply due to huge changes over the years making the change easy to detect, in this case the drop in water usage is less dramatic. Certainty was greatly increased only because of less variability in the difference between the same months of different years.

Once again the p-value chosen is .00269 for a 99.731% confidence level. Between the various time periods, the square sum is 668608. This means the mean squares between the groups is 222869. This means the F Value is 297.1. The mean square of the residual or error is 750. With an F-value of 297.1, the p-value is less than .0001, below the threshold.

Because of this, a different test with fewer comparisons is chosen. Three paired t-tests each comparing the old recording years to the recent ones were made. Each individual test is chosen with a p-value of .000697, so that the family-wide confidence is still 99.731% following the Bonferroni's multiple comparisons test. Comparing the early recording years to fiscal year 2011, the t-value is 18.290, enough to have a p-value below the threshold. The earlier years used on average 82.618 more units of water than fiscal year 2011, for an interval of 67.233 to 98.003. The t-value comparing to 2012 is 18.192, which has a low p-value again. The early years used an average of 88.453 more units, with an interval of 71.893 and 105.013. Third, comparing the early years and fiscal year 2013 has a t-value of 18.024, which has a p-value less than .0001. On average the early recoding years used monthly 86.032 more than fiscal year 2013, the interval is 71.983 and 105.013.

Building: Olin Hall
Building Class: Academic
Construction Year: 1907
Customer ID: 01-0364-000

Table 11. Olin Hall Water Consumption

Fiscal Year	2007	2008	2009	2010	\2011	2012	2013	AVG
July	540	380	380	70	170	180	170	215.625
August	740	240	180	?	480	30	210	276.667
September	480	580	140	180	370	190	200	276.25
October	240	160	100	120	160	90	140	136.25
November	80	160	30	10	50	30	20	42.5
December	?	?	20	20	20	20	20	20
January	120	20	10	1	10	1	10	14.687
February	40	20	20	20	20	20	20	21.25
March	60	40	10	10	10	20	10	17.5
April	?	20	?	20	20	3	130	43.25
May	?	120	100	?	40	80	20	58.182
June	260	200	120	110	70	160	20	105.625
Total	2560	1940	1110	561	1420	824	970	1189.188
AVG	284.444	176.364	100.901	56.1	118.333	68.667	80.333	105.446

The data is all over the place, except for the total water consumption which goes down over time. December consistently has very low usage.
Building: Alden Hall
Building Class: Academic
Construction Year: 1937
Customer ID: 01-0375-A00

Summary: This building consumes very little water and therefore it is concluded that not much attention needs to be given to it.

Table 12. Alden Hall Water Consumption

Fiscal Year	**2006**	**2007**	**2008**	**2009**	**2010**
July	52	54	40	32	5
August	54	70	42	26	18
September	52	82	114	21	36
October	66	60	48	14	32
November	38	48	28	12	11
December	20	?	30	9	10
January	26	36	12	4	3
February	32	18	26	10	10
March	26	24	24	8	9
April	26	?	36	13	9
May	34	?	44	14	26
June	34	50	32	23	12
Total	460	442	476	186	181
AVG	38.333	49.111	39.667	15.5	15.083

Fiscal Year	**2011**	**2012**	**2013**	**2014**	**AVG**
July	25	21	22	7	24.917
August	45	41	42	35	42.083
September	50	44	39	41	47.667
October	28	45	39		39
November	24	17	31		24.85
December	10	12	11		12.563
January	3	6	5		7.55
February	10	11	12		13.05
March	9	9	11		11.8
April	16	19	22		19.5
May	12	14	17		18.125
June	7	4	14		13.8
Total	239	243	265	83	274
AVG	19.917	20.25	22.083	27.66667	23.447

One that that should be noted is that it appears the record keeping is good for this building, even before fiscal year 2011, an anomaly among academic buildings. The extra accuracy and lack of excessive rounding means that conclusions that come from this are stronger. Alden hall does not use much water at all.

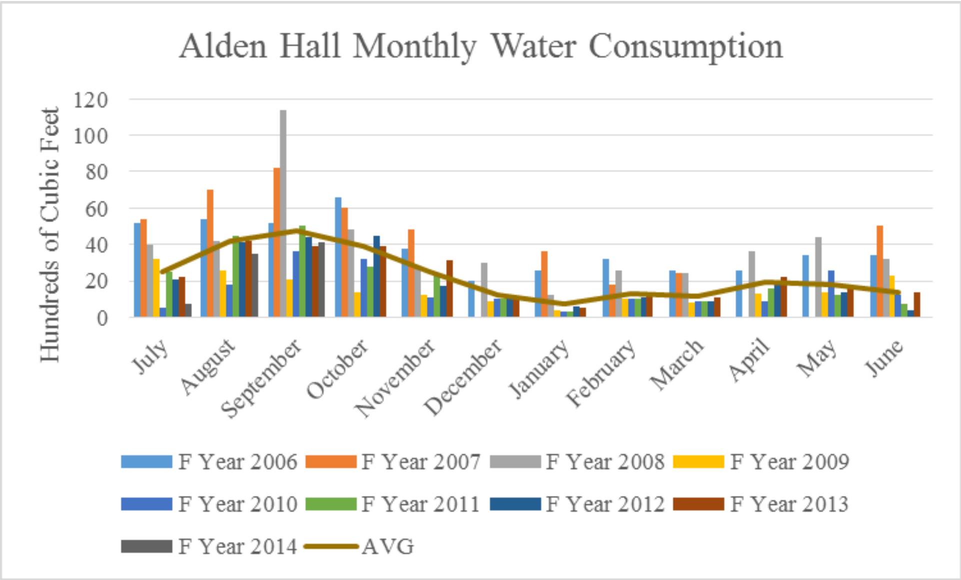


Figure 25. Alden Hall Data Visualized

There is not a lot of variation in the data, but there is the usual trend of less water consumption during breaks, like most of the other buildings.

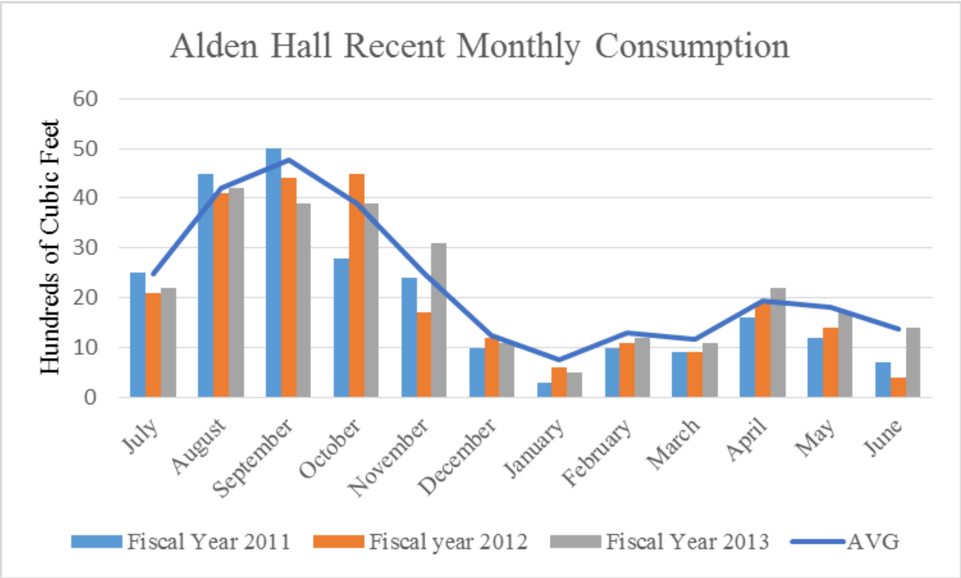


Figure 26. Alden Hall Resent

The thin columns of Figure 25 can be hard to visualize. Here it is easier to see that the water consumption has a local drop during the break months, although the degree is a bit different than the other buildings.

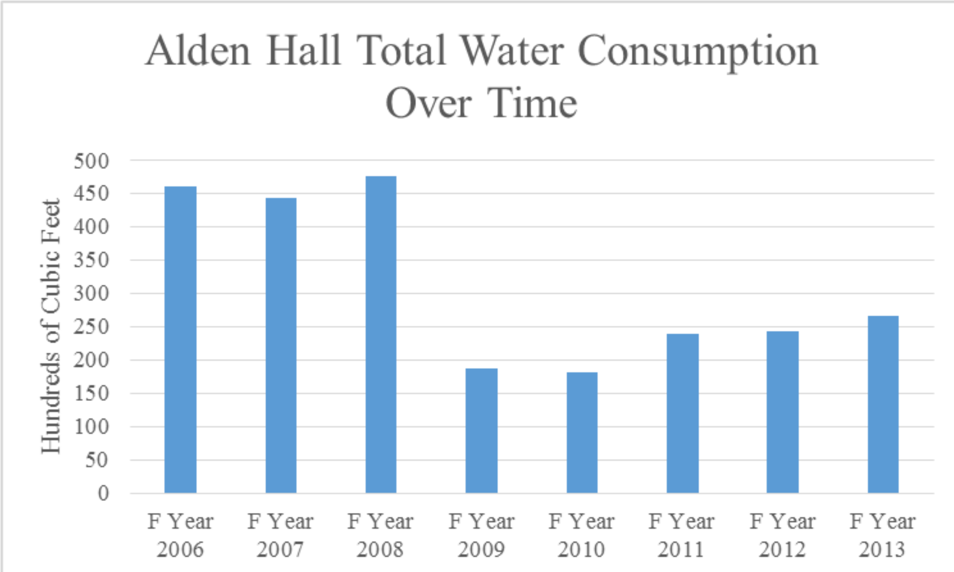


Figure 27. Alden Hall Total Water Consumption Over Time

There was a relatively large drop starting fiscal year 2009, but it leveled off after that.

Like most of the buildings, Alden Hall decreased its water consumption over time. Strangely, it uses more water in the summer than it does in January, a natural low time for most buildings. Since it does not use a lot of water, this quirk can be ignored. The building makes very little difference to the consumption of water by the main campus buildings.

Building: Stratton Hall
Building Class: Academic
Construction Year: 1959
Customer ID: 01-0358-000

Table 13 Stratton Hall Water Consumption (100s of Cubic Feet)

Fiscal Year	**2006**	**2007**	**2008**	**2009**	**2010**
July	40	20	60	?	10
August	160	40	100	?	?
September	60	60	140	20	50
October	200	200	100	40	110
November	720	340	340	380	210
December	680	?	640	620	220
January	820	740	880	450	150
February	860	760	1200	350	170
March	580	980	960	330	170
April	280	?	780	320	150
May	260	?	500	150	520

June	120	240	120	50	10
Total	4780	3380	5820	2710	1770
AVG	398.333	375.556	271	271	160.909

Fiscal Year	**2011**	**2012**	**2013**	**2014**	**AVG**
July	10	20	10	10	18.571
August	10	30	10	10	35.846
September	40	10	10	10	34.667
October	130	10	10		78.571
November	340	10	20		295
December	160	10	10		207.692
January	380	1	1		299
February	170	10	10		279.2896
March	170	10	10		256.428
April	310	10	20		196.154
May	150	10	10		149.231
June	80	10	1		58.071
Total	1950	141	122	30	1793
AVG	162.5	11.75	10.167	10	145.003

This is a lot of water being sued by a math building.

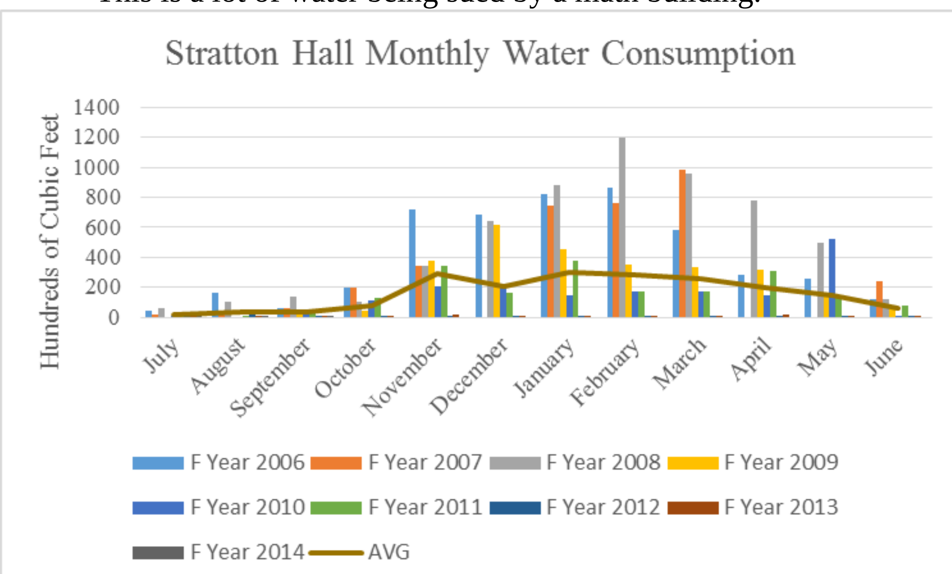


Figure 28. Stratton Hall Monthly Water Consumption

The usual seasonal variation is seen with less water being used during the breaks.

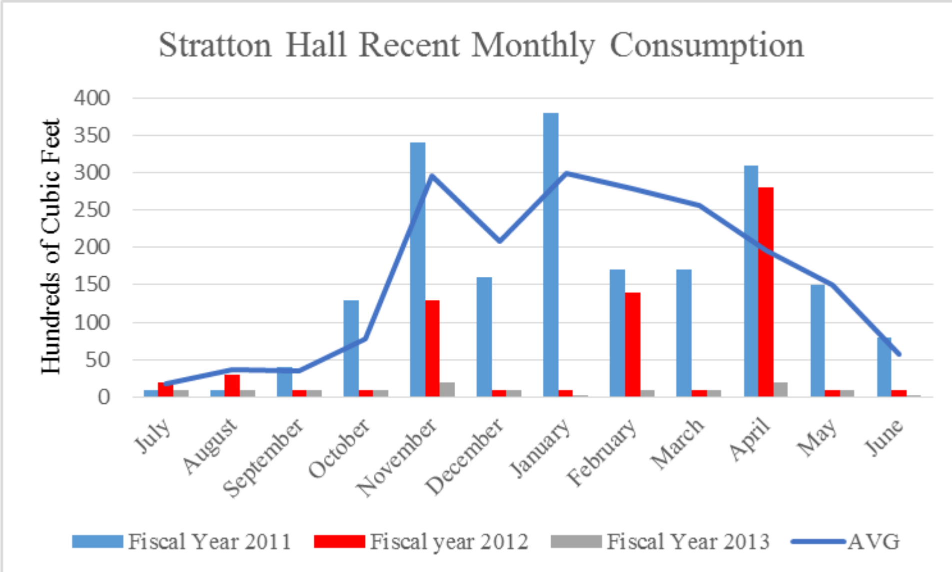


Figure 29. Stratton Hall Recent

The recent water consumption is much less than the historical average. The principal, if not the only cause, is known and it is not conservation efforts. There was a small mistake made by facilities, to be explained shortly.

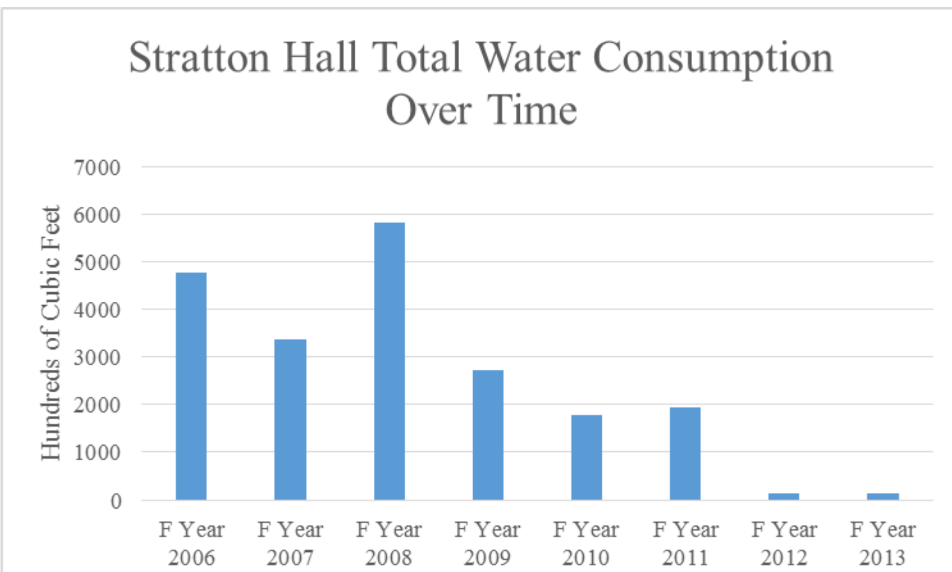


Figure 30. Stratton Hall Total Water Consumption Over Time

It can be seen that in the recent years water consumption has collapsed, consistent with what was seen in the previous graph. The key year is fiscal year 2009.

Stratton Hall consumes a rather large amount of water. This makes sense because it and the power plant are metered together. An emergency valve that let water in from another source was opened. Bill Gradzinsky told a facilities staff member this valve should be shut. While asking him questions it was discovered sometime before fiscal year 2011 and as a result, Stratton

Hall’s water usage appears artificially low recently. Given the data of the annual totals, it would seem that the most likely time for this even would be sometime during fiscal year 2009. This was corrected in our meter tour, but does not show up in our data.

Water consumption is higher in the winter and spring months, often 30 times as much as the average month of a typical year. Regardless of which year, the summer months consume very little. In other words, because the power plant doesn’t use much water in the summer, neither does this account. In effect, the power plant makes the low consumption of the summer months more pronounced. Even in the years the account is partially uncoupled to the power plant, the Stratton Hall doesn’t use much water in the summer since the students are gone anyways.

Building: Fuller Labs
Building Class: Academic
Construction Year: 1989
Customer ID: 12-0293-A00

Table 16. Fuller Labs Water Consumption

Fiscal Year	2006	2007	2008	2009	2010
July	360	200	420	650	60
August	160	340	340	800	470
September	160	200	560	240	330
October	180	500	360	150	140
November	160	180	180	150	80
December	180	?	140	140	80
January	120	360	80	50	30
February	240	220	160	60	80
March	120	180	160	70	90
April	160	?	220	120	80
May	100	?	480	90	150
June	60	180	1400	170	270
Total	2000	2360	4500	2690	1860
AVG	166.667	262.222	375	224.167	155

Fiscal Year	2011	2012	2013	2014	AVG
July	70	20	20	20	99
August	70	12	30	20	116
September	70	70	40	40	109
October	120	30	50		137.857
November	90	50	160		118.857
December	70	100	100		103.846
January	70	70	60		106
February	70	62	80		99.714
March	70	108	80		99.714
April	90	120	150		127.692

May	90	70	50		111.538
June	60	30	50		178.571
Total	940	730	870	80	1350
AVG	78.333	61.833	72.5	26.667	145.982

Unlike Salisbury, Goddard, and Atwater, which are other high traffic main campus buildings, there is no fiscal year 2012 August spike. Other than that, this consumption chart does not look out of the ordinary. In fiscal year 2008, September, December, and May consumed a lot more units than the historical average.

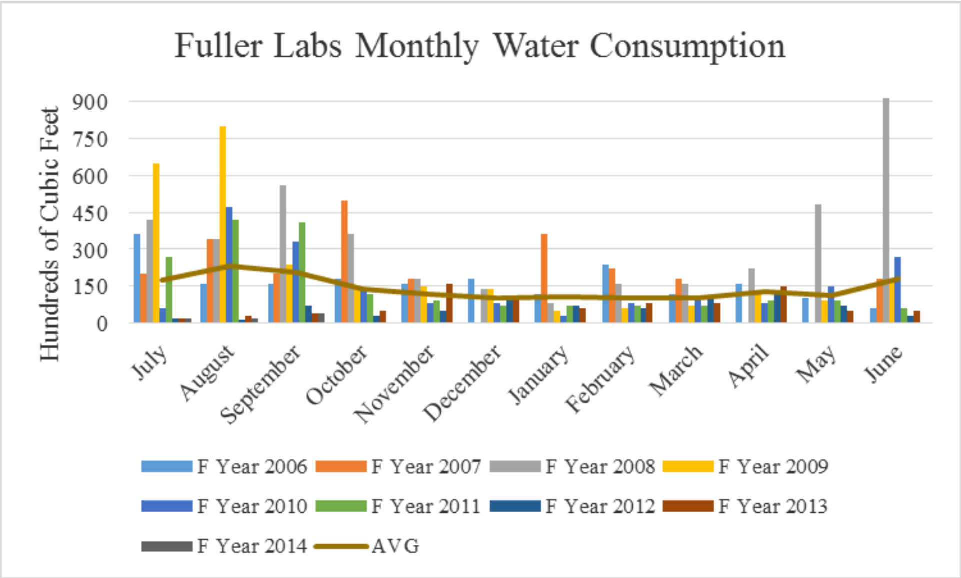


Figure 31. Fuller Labs Monthly Water Consumption

There is no detectable level of seasonal variation to speak of, much like Salisbury Labs.

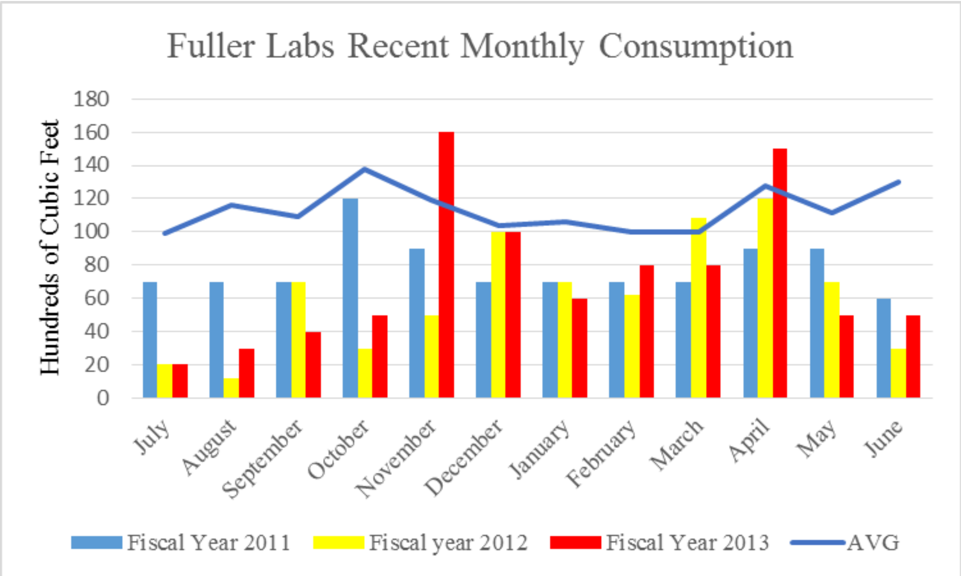


Figure 32. Fuller Labs Recent

The water consumption in recent years has been about level, which the zoom in shows more clearly.

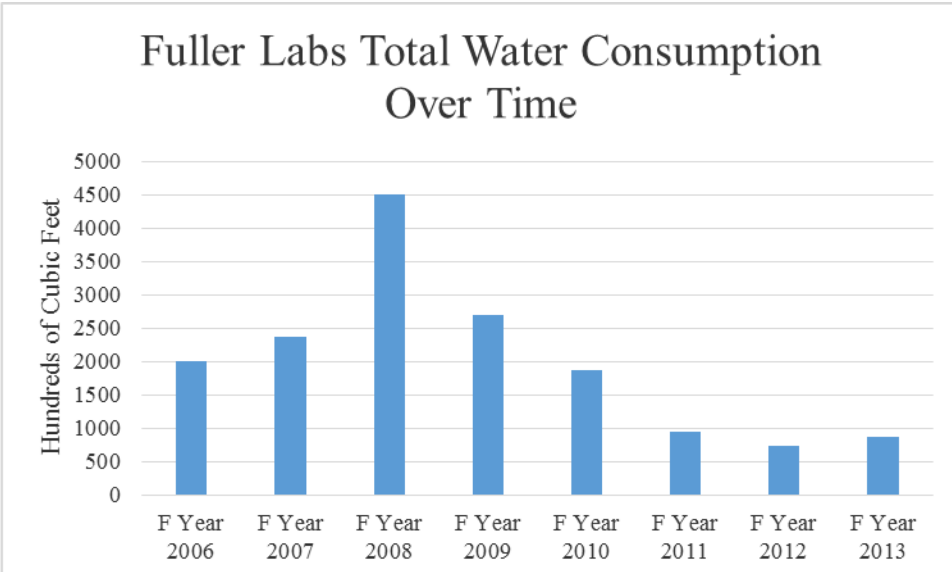


Figure 33. Fuller Labs Total Water Consumption Over Time

It is fairly obvious that fiscal year 2008 has abnormally high water consumption. There is no known explanation for this. Like many of the other buildings, the last three years have had little water usage.

Fuller Labs contains a few large lecture halls and some IMGD classrooms. It does not have an August 2012 spike like the other high traffic main buildings. Other than the fiscal year 2008 spike, this building is not particularly noteworthy. This building has the same water consumption patterns as Salisbury Labs, like flat-lined water consumption within a given year with a few exceptions. First, Salisbury labs has had a major drop in annual water consumption while Fuller Labs has had consumption go up and down, making fiscal years 2011-2014 between the buildings very similar, while before then Fuller's water consumption was effectively a scaled down version of Salisbury labs'. Second, Fuller lacks the previously mentioned fiscal year 2012 August spike in usage. Third, Fuller's higher consumption year within the available records is fiscal year 2008 two years after Salisbury Labs' annual consumption high.

Building: Gateway Park (Gateway One)
Building Class: Research
Construction Year: ?
Customer ID: 14-0161-B00

Table 17. Gateway One Water Consumption

Fiscal year	2010	2011	2012	2013	2014	AVG
July	?	700	300	500	400	490
August	1000	2200	700	700	700	1136.36

September	?	1100	800	300	650	725
October	?	350	400	600		450
November	1300	1050	400	400		685
December	?	1000	300	100		467
January	?	1000	500	200		567
February	900	1000	400	200		570
March	?	550	100	100		250
April	?	1050	300	400		583
May	600	400	400	200		360
June	?	200	600	400		400
Total	3800	10600	5200	4100		6350
AVG	316.667	883.333	433.333	341.667		530

Unlike most of the buildings, even in recent years the data seems to be sloppy. Notice that all of the data is not detailed to five of units. Either the meter man isn’t paying attention or whoever transcribed from facilities was in a rush.

Interbuilding Analysis

A paired ANOVA was performed. The critical p-value is chosen to be .00269 again. The squared sum between the groups, in this case buildings rather than time periods, ended up being 1052136. The mean square of the groups is 350712. The mean squares of the residuals or error is 3001. The F-value is 116.9, which leads to a p-value of less than .0001.

With the global null hypothesis rejected, analysis on the buildings was done with the 99.731% confidence threshold. Dunnett's multiple comparisons test was done to see if the other buildings were different from Salisbury. Comparing Salisbury Labs to Atwater Kent Labs yields a q-value of .171. The null hypothesis is accepted. SL uses from. On a monthly basis, SL uses from 11.097 less to 9.783 more units of water. Effectively SL and AK are equivalent in water use over the long run. Comparing Salisbury Labs to Goddard Hall has a q-value of 11.49. This means the p-value is less than .0001 and is significant. Salisbury Labs uses from 33.7 to 54.66 fewer units of water per month than GH. Finally SL to Higgins Labs is compared. The q-value of this test is 6.983. This is statistically significant and leads to a low p-value. Constructing the interval again, Salisbury Labs uses 16.44 to 37.32 more units of water monthly than HG.

A paired t-test on the data from fiscal years 2011-2013 was done on the water consumption between the buildings. The t-value was 2.211. The standard error of the differences was 15.215. The difference of water consumption between the buildings was 1.918 to 93.208 units of water.