YALE UNIVERSITY

Analysis of Potable Water Use at Yale University

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EXECUTIVE SUMMARY

- Yale University uses an average of over 600 million gallons of water every year
- The number of water meters Yale uses has increased over the past seven years, but the accuracy of those meters has decreased. Water infrastructure information has become fragmented, and the locations of water meters for many buildings are unknown.
- Accurate data is essential for monitoring any sustainability indicator. Calculating water consumption per building, per building floor space, and per building occupant is possible for some buildings, but must be improved.
- To improve accuracy of consumption data, the University must begin internal water monitoring, ideally for every academic building, laboratory and dormitory. This will also require development of a monitoring program to ensure that adequate data are taken over multiple years.
- A complete map of the potable water infrastructure should be compiled.
- A protocol for mapping irrigation systems and estimating their water consumption should be developed.
- A system for informing water consumers within buildings of their calculated per-person use should be developed; this is especially important for residential colleges.

INTRODUCTION

As part of the Land, Water and Biodiversity Assessment, Yale University seeks to further its commitment to sustainability by establishing indicators for monitoring and grading potable water use and consumption. This report is the first attempt to describe, as completely as possible, what is known about the University's water consumption and how that data might be used for sustainability indicators. To that end, data primarily in the form of water usage billed to Yale were collected, amalgamated, and analyzed. An initial goal was to determine use by each individual building, and as a secondary goal, total use by activities such as irrigation, sanitary use, or food preparation in dining halls. However, Yale is complex place and its water infrastructure in some cases is a century old. As the data were closely examined, uncertainty in the reliability of those data arose.

The resulting report, presented below, is meant to describe the available data and various problems with them. Some initial metrics have been developed, as was the original plan, but it is more important that the accuracy of those metrics is contingent on having accurate data in the first place. There is a proliferation of water meters that have either malfunctioned or been removed. There are meters whose destination buildings are no longer certain. There are several lost pipes, multiple buildings that are not connected to any meter, and some meters that were not associated with any listed building.

Yale owns properties throughout New Haven and New England. Although some data are available for those areas, the sum of this is inconsequential when compared to the core areas of the University. The study instead focuses only on those core areas.

At least some data are available for each fiscal quarter from the beginning of Fiscal Year 2003 through the present. For Yale, Fiscal Years begin on the first of July and end on the 30th of June of the following year. This means that “Fiscal Year 2003” began on July 1st, 2002 and ended on June 30th, 2009. Each fiscal quarter corresponds to a calendar seasonal quarter, such that Fiscal Quarter 1 2003 is actually summer 2002, Fiscal Quarter 2 2003 is fall 2002, Fiscal Quarter 3 is winter 2003, and Fiscal Quarter 4 is spring 2003. As most data are presented quarterly, fiscal quarters provide the basic time division for this report.

Introduction to Yale University's Water Infrastructure – The Four Campuses

Yale University owns or rents over four hundred buildings. While the majority of these are within the city of New Haven, Connecticut, there are other properties outside the city or the state. Almost every one of these buildings uses water for more than one type of activity. A typical residential college, for example, uses water for sanitation, domestic activities such as showering, and for food preparation in dining halls. A building labeled as a laboratory might use water for wet chemistry, plant propagation, or simple equipment cleaning. If is any landscaped ground adjacent to any given building, then that building may or may not be attached to an irrigation system. The density of the Yale campus is such that multiple buildings may share water infrastructure. And, at every point, there might be hidden leaks or diversions from this infrastructure which add water consumption to the University's overall bill.

Yale is comprised of four major campuses, as well as peripheral and rented properties, which have largely been purchased in or built into different parts of New Haven over the course of many decades. The four main areas are referred to as the Central Campus, the Athletic Fields, West Campus, and the Medical Campus. All of the buildings in these areas draw their potable water supplies from the same municipal utility. However, water supplies are delivered and metered in different ways for each area. In the Central Campus, most individual buildings are supplied by individual lateral pipes that come from the municipal mains underneath the street. However, many buildings are large enough that they require multiple supply laterals, while some other buildings share water from a single pipe. Due to this huge diversity of building types, tracking water use for individual buildings is difficult.

The Medical Campus is, by comparison, highly centralized. Most of the potable water distributed to the core areas of the medical campus circulates through Sterling Power Plant, which also provides chilled water, steam and electricity to those buildings. Water use for the Medical Campus is, for the most part, aggregated into a single value, and precisely determining water use for an individual building is often not feasible. However, there are several large buildings in the vicinity of the Medical Campus that are separate from this system.

The Athletic Fields include actual outdoor irrigated lawns as well as buildings adjacent to them. Meters are often labeled by the building to which they are attached, although the bulk of water consumption is in fact for large landscaped areas outside of the buildings. Irrigation is also supplemented by annual precipitation, and therefore water required for irrigation tends to fluctuate wildly from year to year. The Athletic Fields also feature some significant differences in the method of discharge of some of its used water; for example, runoff from the Yale Golf Course flows into the central water feature, which also serves as a pool for irrigation supplies.

Finally, the West Campus, purchased by the University in 2007, is a thirteen-acre industrial science complex with its own power plant. It is similar to the Central Campus in that some individual buildings have their own water meter accounts apart from the power plant, but it is much smaller and more centralized.

Compounding the overall complexity of the University are the various tenancy relationships between Yale and private enterprise within New Haven. Yale owns and occupies many buildings, but it also rents and leases buildings to and from different organizations for a variety of purposes. In other cases, Yale hires private companies to operate or manage its properties. This means that Yale's "total water use" is subject to definitions of ownership. If we wish to know the total amount of water purchased by Yale, then we need only to look at the available water bills. If we wish to know the total amount of water used for Yale's physical properties, then we require the bills paid by Yale's lessees as well. If we wish to know the total amount of water used by Yale's employees, business operations, and attending students and scholars, then we need more data than one would possibly be able to gather.

AVAILABLE DATA

WATER CONSUMPTION DATA

Yale's domestic potable water is supplied by the South Central Connecticut Regional Water Authority. Almost all available water consumption data are from bills sent by the RWA. For the seven fiscal years which were examined, Yale has been billed for 160 and 250 water meters for all four major campus areas. Accounts have been added or removed as the University has added new buildings or renovated existing ones. Most billed meters are for buildings that are owned and occupied by Yale. University-owned buildings which are leased to private individuals or are managed by third parties are, for the most part, not billed to Yale, although there are several exceptions.

Meters serviced by the RWA are billed quarterly. Each account is a summed grouping of individual meters. Accounts are listed by "premises," or a city block listed by an adjacent street name. For example, Science Hill water meters are grouped together in the "Edwards Street" account. There are two types of fees for each meter. The first is a flat-rate service charge that is dependent upon the size of the lateral pipe from the water main. The second is a per-unit consumption charge billed in units of hundreds of cubic feet, or "CCF." RWA bills list additional data for each meter such as: ID numbers for individual meters; a brief description of the location of the meter's "touch" readout pad or data port box; bill start and end dates; whether reported data were based on actual readings or estimates; and WPCA codes, or suffixes for the meter numbers that the Greater New Haven Water Pollution Control Authority uses to determine sewage rates. The data available on the bills are summarized in Table 1 below.

Table 1 – Types of data available from an RWA bill. The information below is for the meter for Welch Hall.

Type	Description	Example
Account #	Account number	691500018
Premises	General area of accounts	206 ELM ST

Seq	Account # suffix for indiv. meter	01
Meter Size	Size of pipe connection	2”
Meter Number	RWA ID number for meter device	0007701538
Meter Location	Transponder signal ID and/or location of data port	MXU#1151476-PHELPS GATE
SRVC Charge	Flat-rate charge based on size	109.59
Consumption	Consumption for meter in CCF	6758
Total Cons.	Consumption for account in CCF	10290
RD CD	Estimated or Actual reading	E
From Date	End date of previous reading/bill	11/28/2008
To Date	End date of current reading/bill	02/28/2009
From Reading	Meter value at previous reading	31047
To Reading	Meter value at current reading	37805
WPCA	Suffix for sewer bills	02

Unfortunately, data are not complete for the entire time period studied. The information displayed in Table 1 is only displayed on individual RWA bills or combined bill statements. Copies of individual bills are not available, and copies of combined statements only exist for ten fiscal quarters (FQs): FQ2 2006; FQ1 2007 – FQ4 2007; FQ2 2008 – FQ1 2009; and FQ3 2009. The combined statements contain the bulk of Yale’s metered accounts, but exclude about 40 meters for different facilities.

Records of previous billed usage are entered into EnergyCAP, a software suite specifically designed for utility financial management. Only dates, consumption rates, service charges, consumption rates and charges and some meter location information are recorded from RWA bills in this database. Information that is used exclusively by Yale is added to the bill records in E-CAP. These include financial tracking information, campus areas, Yale-only meter identification numbers, building types (i.e., “academic” or “athletic”), and assumed destination buildings for the meters. Yale meter IDs are comprised of a categorical prefix for water meters, Yale Facility ID numbers for each building and a numbered suffix for each individual meter at or near that building. The single meter at Sage-Bowers Hall, for example, is listed as WA-RWA-1070-001. Destination buildings were determined by the Office of Facilities. E-CAP also stores “split percentages,” or an estimate of the relative percentage of water consumption by multiple buildings that are fed by the same meter; however, these were not included in this analysis. Queries of the E-CAP database were used to supplement RWA combined statements.

Some of the data in E-CAP are publicly accessible via the Energy Explorer, a web-based Java application.[1] Data were downloaded from the Energy Explorer to supplement copies of RWA combined statements. Catherine Triplett, Senior Financial Manager for the Office of Facilities, provided both copies of the RWA combined statements and queries of the E-CAP database. Bob M.

[1] Accessible at http://www.facilities.yale.edu/public/Energy.html

Sessions, Programming Analyst for Facilities, provided queries of the data that are used for the Yale Energy Explorer program.

Supplementary consumption data is available for the Medical Campus. Three RWA meters are designated as flowing to Sterling Power Plant. The combined flow from these three meters is divided between water for SPP itself (i.e., to make steam for electricity generation and heating or for chilled water for cooling) and the potable water distribution system for the core area of the Medical Campus. Robert "Jess" Muir, the Chief Engineer for Sterling Power Plant and Facilities, provided daily data measured by internal meters within SPP for 2006 and after. This data was used to calculate the consumption for power plant operations. The difference between RWA billed consumption and power plant consumption is water use by the core Medical Campus buildings. These were compared to calculations for previous years as made by the Office of Facilities (using different date ranges). Calculations for previous years, also using Mr. Muir's data, were provided by Catherine Triplett.

SPATIAL DATA

Detailed data for every building in the University are available. These data include building type, street addresses, dates of completion and renovation, and building size expressed as square footage. There are three types of measured square footages: Gross Square Footage (GSF), or floor space calculated from building exterior wall length; Net Square Footage (NSF), or floor space calculated from building interior wall length; and Assigned Square Footage (ASF), or the amount of NSF that is currently assigned for any type of use. Most buildings also have values for the number of available stations, or estimates of building capacity for occupants for categorical types of use (for example, a shared office capable of holding two graduate researchers would have two "office stations," although there would not necessarily be two people using the office). These data were provided by Elizabeth J. Anderson, the Manager for Space Management and Information Systems, part of the University Planning division of the Office of Facilities. She also provided a provisional list of changes in building GSF due to additions and renovations, although this list has yet to be completed.

BUILDING TYPES

Categorical classification of buildings is necessary in order to determine the primary water-consumption activity for each building. Building classifications are present in both spatial data and information from E-CAP. Classifications for each building were primarily taken those in E-CAP. One of the categories, however, was too broad to be use effectively for comparisons. The "academic" category encompasses all buildings that are used for instruction, faculty offices, or scientific research. A new category, "laboratory," was created for buildings that are assumed to be dedicated primarily to scientific research. Buildings that did not fit any of the classifications were classified as "other". When primary use for a building was uncertain, it was re-classified as "mixed use." A complete summary of the use categories follows.

- **Academic** buildings are used primarily for educational activities such as instruction. Typical users are students and school faculty. Principal uses of water in these buildings are assumed to be for restroom use and/or outdoor landscaping.
- **Apartment** buildings are the residential apartment complexes owned and operated by the University. Their occupants are full-time residents. Primary water consumption activities are for domestic activities, i.e. bathing, cooking, and toilet use.
- **Administration** buildings are the University's business offices. The primary water use in these buildings is assumed to be for restroom use and/or outdoor landscaping. .
- **Athletics** facilities are both athletics buildings, such as Payne-Whitney Gymnasium, and outdoor facilities, such as Yale Field. The most significant water use for each facility is dependent upon whether the facility is indoor or outdoor. Yale Field primarily uses water for irrigation, while PWG uses water for diverse activities such as locker room showers, swimming pool maintenance, etc.
- **Assembly** buildings are performance-oriented buildings such as Woosley Hall. Water use for these buldings is intermittant restroom use, and is often low compared to the other categories.
- **Dining** facilities refer to only two independent dining halls, Donaldson Commons and University Commons. Water use for these two buildings is dominated by dishwashing and food preparation.

- **Dormtories** include graduate housing buildings such as Helen Hadley Hall or any of the Residential Colleges. Water use for these buildings is likely dominated by water for toilets and showers, but can be higher where laundry and dining facilities are included in the dormitory.
- **Housing** buildings are large houses maintained for certain University personell, such as the University President's house at 43 Hillhouse Avenue.
- **Laboratories** refer to buildings that are dedicated mostly towards scientific experimentation. Specific water use activities can vary immensely from building to building, or even from room to room. The University's greenhouses are included in this category.
- **Library** facilities include Yale's libraries, museums and special collection buildings. Many of these facilities require large amounts of water for humidity control.
- **Mixed Use** facilities refer to buildings that are combinations of two major categories, or contain offices or divisions that are leased to private individuals or businesses.
- **Operations** facilities are buildings that are run by the Office of Facilities or Grounds Maintenance for storage or as small offices or as warehouses and garages.
- **Hospitals** refers mostly to the Yale University Student Health Center. The majority of Medical School facilities are either Laboratory or Academic type facilities, and are not included in this category.
- **Power** facilities principally refer to the two major power plants in the core campus area. In the Office of Facilities' spatial datasets, power plants are categorized as Operations buildings; here, they are separate to avoid confusion between buildings that use water for electricity and steam generation and those that use water for other types of activities.

Two special categories are included for categorical calculations from FY 2007 and on: "Medical Buildings," or the collection of laboratories and academic facilities in the core Medical Campus, and "Medical Power," or Sterling Power Plant. No buildings within the core Medical Campus are independently or internally metered, so none could be disaggregated and reclassified within another category.

MAPS

Because many of Yale's buildings have been renovated, razed or rebuilt over the past decade, information regarding the location of many of the University's internal water distribution pipes has become fragmented. Some of the destination designations for meters are uncertain. Underground utility maps were used to determine some destinations. In many cases, maps had to be supplemented with on-site inspections; in other cases, designations were simply best guesses. (A discussion of related issues is included in the "Case Studies" section of this report.) Maps, printouts of CAD drawings, and GIS data, as well as access to the Yale Plan Room, were provided by the staff of the Information Systems division of the Office of Facilities: Sean Dunn, the Information Resources Manager; David Kula, the CAD Team Leader, and Chiang Pin Su, CAD Engineer.

POPULATION DATA

Little population data on a per-building level is available, and there is none at all for years past. It may be possible to develop estimates of average populations based on station data, but the assumptions that would be involved have not yet been developed. However, because student enrollment records are readily available for the Residential Colleges, higher quality per-person water use for these buildings can be calculated easily. Detailed enrollment data for each building were provided by John Meeske, Associate Dean for Physical Resources and Planning for Yale College. These data are for each fall and spring semester of every year; they do not include summer session enrollment data. Occupancy of the college buildings was directly listed for semesters from the Spring 2007 term through the present. Occupancy for semesters before Spring 2007 was calculated by subtracting the number of freshmen living in the Old Campus dormitories and the numbers of upperclassmen living off-campus or in annex dormitory space from the total number of students for each college. The summary of population data for the colleges is included in the “RESCOLL” tab of the spreadsheet.

METHODS

DATA ORGANIZATION

Data from the ten copies of RWA combined statements were used to establish a “backbone” of established accounts. All calendar quarters from summer 2002 (the beginning of Fiscal Year 2003) through spring 2009 were used as a horizontal date range in an Excel spreadsheet. Meter consumption data from the ten billing periods for the combined statements were entered under the closest calendar quarter for each. Additional information from the combined statements, including account premises, meter location information, meter addresses, meter size, and date ranges were entered for each as columns appended to the consumption and quarter ranges.

The values for the remaining 18 quarters and associated Yale-specific data were obtained from E-CAP queries or downloaded through the Energy Explorer. Meters listed in RWA combined statements and in E-CAP had no common designation. To make a complete time series, sequences of known consumption values from combined statements were found in E-CAP data. The associated E-CAP values for the rest of the series, as well as Yale meter ID and destination building information was appended to the existing series.

The spreadsheet containing the concatenated data quickly became unwieldy, so a color-coding system was employed. In the attached spreadsheet, values from E-CAP are shaded blue. Values confirmed from combined statements are shaded gray.

ESTIMATES

To measure overall accuracy, an analysis of the percentages of estimated data was necessary. This began with recording known estimated consumption values. For copies of available RWA statements, values were denoted as “estimated” or “actual”. For all other entries, whether a value was estimated was determined by patterns of usage for each individual time series of data. Because estimated accounts typically repeat the same consumption value over many consecutive quarters, quarters showing this pattern were flagged as probable estimates using the following rules:

- When a confirmed estimated value from a combined statement was repeated in an adjacent quarter;
- When a three- or more digit number repeated more than two times in a sequence (unless the ending digits were zeroes);
- When a two-digit number repeated more than three times in a row; or
- When a negative value of immediately followed a positive value of the same magnitude, effectively canceling it out.

The total numbers of confirmed estimates, actual values and *estimated* estimates were tallied and reported for each quarter, as were as the total amounts of consumption for each category for each quarter. These calculations are shown in the “ESTIMATES” tab of the attached spreadsheet.

On the attached spreadsheet, confirmed estimated values were shaded yellow.

NEGATIVE VALUES

Negative values for quarterly consumption are common. They represent credits for over-billed usage for individual meters. However, they cause two types of distortions in calculations. First, they make the summed totals for a quarter lower than it should have been, as the erroneous consumption occurred in the previous quarter. Second, for the same reason, they cause summed totals for previous quarters to be overestimated. It is often uncertain which quarters negative values are applied to, or how they were calculated. Negative values have been highlighted in orange in the master spreadsheet.

To examine the effects of negative values on overall usage statistics, three methods of summation were used. The first was a simple sum that includes all negative values as they are listed. The second was a sum that excluded any negative value. The third involved subtracting each negative value from past consumption for the meter and then removing the negative. Values were adjusted according to these rules:

- If the credited consumption for a quarter was equivalent to the amount in a previous quarter, both quarters were replaced with a zero value.
- If the credited consumption for a quarter was preceded by a series of estimated values that, when summed, were equivalent to the credited consumption, then all of these entries were replaced with a zero value.
- If the credited consumption for a quarter was followed by a series of estimated values that did not qualify for Rule 2, then the credited value was divided by the number of preceding estimated values in series. This amount was subtracted from each of the preceding estimated quarters. The negative value was replaced with zero.
- If none of the above rules were satisfied, then the credited amount was subtracted from the preceding quarter. The result, if negative, was then replaced with zero, and the remaining amount subtracted from the next previous value, et cetera.
- In two special cases, there were glaring inaccuracies in water consumption rates that could not be reconciled using the rules above and the existing data. Values for these particular accounts were replaced with estimates based on assumptions regarding historical usage. These were for Sage-Bowers Hall and Sterling Memorial Library.

These three methods produced three datasets that could be used for other calculations. Each was selected depending on the analysis being performed. In general, the first method gives a lower-bound underestimate of water consumption. It is the method currently used to calculate the University's total water consumption. The second produced an upper-bound overestimate of water consumption. The third provides a "smoothed" dataset that was more useful for observing changes in consumption over time and for calculating per-square-foot and per-person consumption rates.

Original, unadjusted data are shown in the "ALL" spreadsheet tab; sums using the as-is data, and excluding negative data, are below. The adjusted data are in the "ADJUST" spreadsheet tab. Values that have been adjusted are shaded green.

TOTALS

Totals for the four campus regions using each of the three methods described above were calculated. Totals were calculated for four main campus areas: Central Campus, the Medical Campus, West Campus, and the Athletic Fields area. Other peripheral properties owned by Yale that are not in any of these campus areas were excluded from these, and all other, totals. Totals for categories of building use were calculated using adjusted data only. Totals for individual buildings with multiple meters were calculated by summing the meters; these buildings are designated with a proxy Yale Meter ID number that ends in “SUM” for some calculations. Totals for the campus areas for each of the three methods of calculation are displayed in the “SUMMARY” tab of the spreadsheet. Calculations of categorical totals are displayed in the “TYPES” tab.

WATER CONSUMPTION PER SQUARE FOOT

Total water consumption per square foot is a common calculation used as an indicator for water use intensity and sustainability. It is, simply, the total consumption of a building during a given time period divided by its gross square footage. Total consumption for buildings with multiple meters was calculated as indicated above, where necessary. Total consumption was divided by the GSF of the associated building, where available. If one or more meters were attached to multiple buildings, then the sum of the GSF of all of the buildings were used. The resulting values were converted into gallons per square foot. Both the original and adjusted datasets were used for comparative purposes. Calculations from the original values are in the attached spreadsheet in the “SQFT” tab; those from adjusted values are listed in the “SQFT2” tab. Original Water consumption per square foot for power plants, the medical campus buildings, and athletic fields (but not athletic buildings) were excluded.

Yale has added many square feet to its existing buildings over the past decade. To address this, renovation years during which buildings were expanded were ignored for those respective buildings. Current values for GSF were used for the “after” years, while differences of the current GSF and the addition GSF were used for previous years. This resulted in year-long gaps in this metric for buildings that were nevertheless using water for the year of construction in question.

Unfortunately, reliable consumption data, accurate destination designations and GSF data are not available for all buildings. Only those buildings which had sufficient data in all three categories were included. Averages were calculated for each building for quarters and for fiscal years. Averages of these values were taken to determine categorical averages. It should be noted that the number of buildings included in each average changes from year to year.

WATER CONSUMPTION PER PERSON

Building water consumption can be expressed as a volume per person per unit time. This metric is used as a standard for measurement and monitoring of institutional water use. Because of limitations in building occupancy data, a University-wide analysis was not performed. However, Residential College occupancy is well-recorded for the period of the study, so an analysis on these buildings was performed.

Adjusted consumption for meters for each of the colleges was summed for fall, winter and spring calendar quarters and divided by the corresponding number of students assumed to be enrolled during that time period. Yale College semesters do not match up well with RWA billing quarters, so the divided data had to be treated carefully. The "fall" quarters (Q4), which run from the beginning of September until the middle of November, were divided by fall semester student population numbers. "Spring" quarters were similarly divided by the Spring semester student population. Summer quarters were ignored, as summer session enrollment data were not available. "Winter" quarters begin in November and end in February of the following year, and consumption amounts for these quarters were divided by Spring semester student populations. This is because population data is assumed to be collected at the beginning of each term. Those values usually decrease as time goes on as students move out of the college. This means that, for the fall term, there would be fewer students in a college November than there were in September. Additionally, winter semester populations are recorded during January, which is between one and two months from the end of the winter calendar quarter.

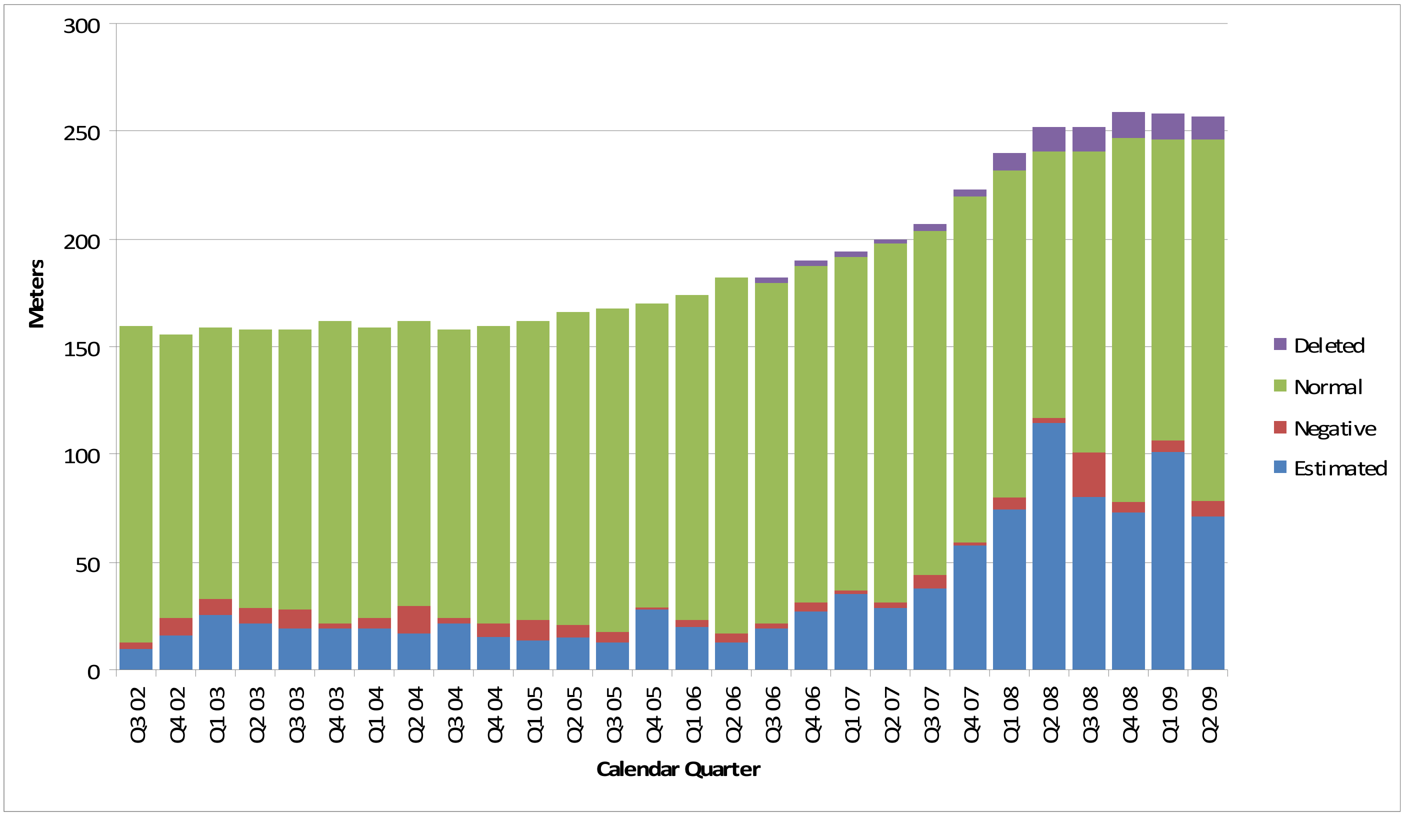
The table of student population in each college by quarter, and the table of calculated gallons per quarter per student, is displayed in the "RESCOLL" tab of the spreadsheet. Years where a college was under renovation are colored orange. Student populations for winter quarters, and corresponding calculations, are highlighted in red text to indicate that the values are copied from the subsequent spring quarter and are not actual measured values.

RESULTS

ANALYSIS OF ESTIMATED AND NEGATIVE VALUES

Analysis of estimates revealed that the number and proportion of accounts that are estimated or are otherwise faulty have increased steadily over the past seven years. At the beginning of FY 2003, Yale maintained only 160 (known) accounts, only three of which reported negative values. The percentage of suspected "estimated" meters was 6.25% of the total number of meters for this period. By the end of FY 2009, Yale maintained 246 accounts, with at least 29% based estimated values. Calendar Q1 2009, the last quarter for which a combined statement was available, reported 101 estimated accounts, or 41% of the total. Furthermore, by this time were also 11 "legacy" meters, or meters which have been disconnected or replaced by the RWA. However, bills were still reporting service charges for those meters during many quarters after their destruction date. It is clear that Yale is adding more and more water accounts as time goes on, but that the inaccuracy of those accounts is increasing, as shown in Table 1.

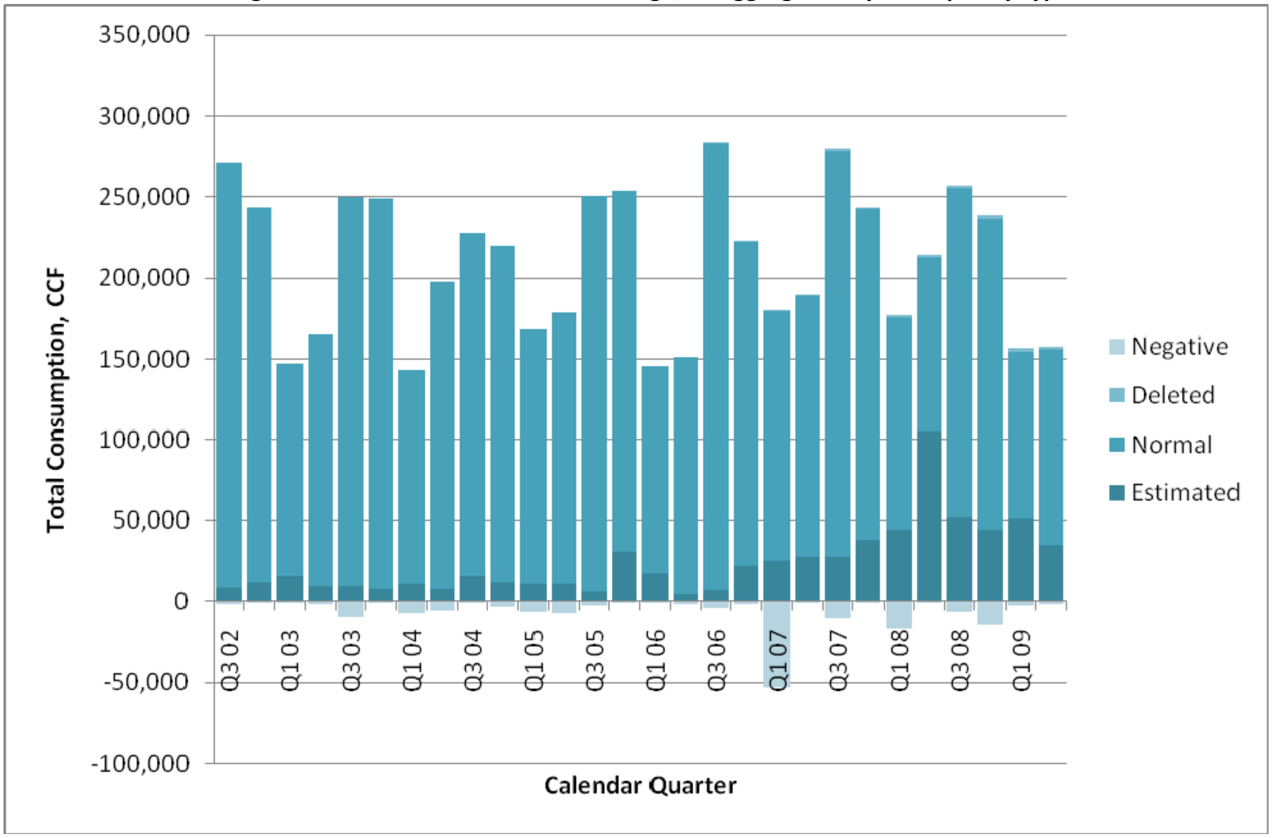
Figure 1 - Summary of total quarterly meter readings, with number accurate, deleted, negative, or estimated



A similar chart of estimated, normal, negative, and deleted consumption, however, shows that the magnitude of some of the "bad" meters is relatively small. Many of the estimated or negative meters, however, represent relatively small amounts of water usage. Cumulative negative amounts, or credits, for all quarters, average only 3% of the total non-negative billed usage, although there are errors that can significantly distort the total amount of water consumed: Q1 2007 recorded negative consumption for a total of 52,957 CCF, or 30% of the total of non-negative values for the same quarter. Nevertheless, Figure 2 shows that although credited water consumption is generally small compared to the amounts of estimated consumption. Estimated consumption increased steadily from 2007 – 2008, and reached a high in spring 2008.

Although the amount of estimated billed water use has increased, the change from Q3 2002 may be exaggerated due to an undercount of estimated values. This implies an overall breakdown of water meters, or an insufficient response in replacing them.

Figure 2 - Cumulative billed water usage, disaggregated by data quality type

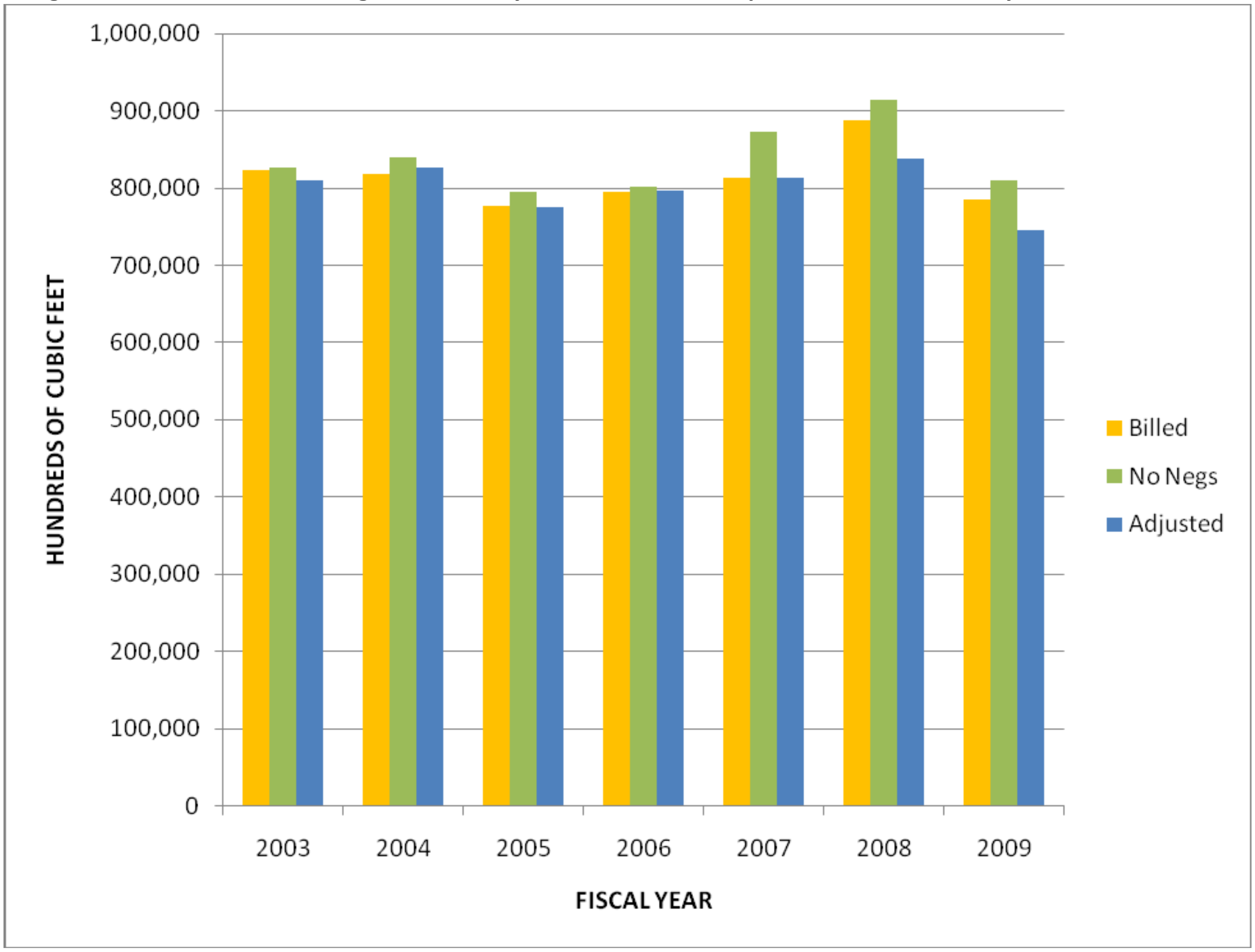


Despite the inaccuracies, Figure 2 accurately shows the basic pattern of water use at the University. Consumption peaks in the third quarter of each year, which corresponds to the period from late May through late September. Usage increases due to higher evaporative losses in the University's thermal power plants during summer. Increased consumption due to summertime irrigation of landscaping also contributes to this number, although the contribution is much smaller. Water use is lowest in winter quarter, which corresponds to late November through the end of February. During this period, evaporative losses in the power plants are much lower, and faculty, staff and students are not present at the University for weeks during the holidays.

TOTALS

Total consumption for each quarter and fiscal year were summed according to the three methods described above. In terms of cumulative consumption, the different methods resulted in only small differences for FY 2003 – 2006; however, the last three years display larger differences between the three values due to the epidemic of broken, replaced, or credited water meters. These relative values are shown in Figure 4.

Figure 3 - Total Billed, Non-negative, and Adjusted water consumption for Yale University, Fiscal 2003 - 2009



Closer examination of individual data points shows the high variability of these summed statistics. For example, the billed usages from FY 2003 and FY 2009 were 822,449 CCF and 784,783 CCF, respectively, a decline of 37,666 CFF (over 28 million gallons). However, FY 2008 billed usage was the highest on record, at 888,225 CCF. The non-negative sum and the adjusted sum for that year were also highest for their respective categories.

Averages for the seven-year billed, non-negative and adjusted sums were all over 800,000 CCF, with the non-negative sum highest at 837,394 CCF and the adjusted sum at 800,534 CCF. Standard deviations for each series were taken; the smallest was for the adjusted series. Results are displayed below in Table 3.

Table 2 - Summary of total consumption, FY 2003 - 2009, using three methods

Fiscal Year	2003	2004	2005	2006	2007	2008	2009	Average	σ
As Billed	822,449	817,566	777,562	795,372	814,079	888,255	784,783	814,295	36,801
Non-negative	827,304	840,061	795,016	801,039	873,220	914,860	810,259	837,394	43,296
Adjusted	810,160	826,940	774,648	796,834	812,543	837,531	745,084	800,534	31,784
Change Negative	4,855	22,495	17,454	5,667	59,141	26,605	25,476	23,099	18,193
Change Adjusted	-12,289	9,374	-2,914	1,462	-1,536	-50,724	-39,699	-13,761	22,640

CAMPUS AREA TOTALS

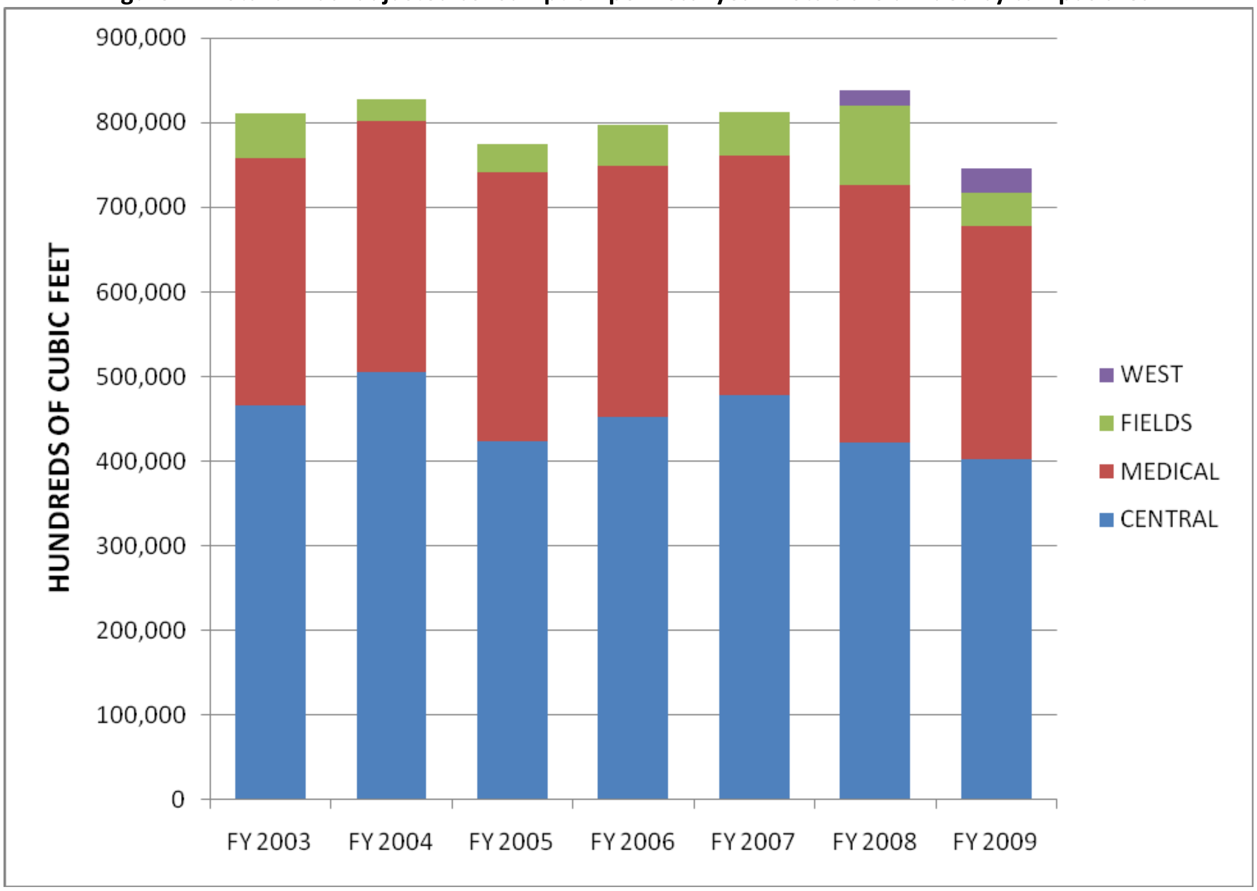
Unsurprisingly, disaggregating the totals by campus area revealed that the Central campus is the largest water-consuming campus area, at an average of 56 – 57% of the total, by any method used. The Medical Campus consumes approximately one third of the total, and the Athletic Fields 6%. The averaged data are biased against the consumption for the West Campus, which was only added in FY 2008. For an average of FY 2008 and FY 2009 only, the West Campus represents 3.6% of total annual usage, the Athletic Fields 5.0%, the Medical Campus 35.4%, and the Central Campus 55.9%. Summary results are displayed in Table 3.

Table 3 - Consumption by campus area using three methods, FY 2003 - 2009

Area	FY2003	FY2004	FY2005	FY2006	FY2007	FY2008	FY2009	Average %
BILLED	CCF	CCF	CCF	CCF	CCF	CCF	CCF	
Central	476,200	499,056	425,791	451,326	479,754	472,483	442,154	57.0%
Medical	295,256	293,417	319,159	296,345	283,396	304,057	275,883	36.3%
Fields	50,993	25,093	32,612	47,701	50,929	93,708	38,911	6.0%
West	0	0	0	0	0	18,007	27,835	0.8%
NO NEG								
Central	478,874	513,920	440,792	456,979	537,477	483,894	464,870	57.6%
Medical	295,523	297,752	321,182	296,359	283,396	319,042	276,081	35.7%
Fields	52,907	28,389	33,042	47,701	52,343	93,708	39,525	5.9%
West	0	0	0	0	0	18,216	28,313	0.8%
ADJUSTED								
Central	466,374	504,562	422,891	452,774	478,216	422,149	402,469	56.2%
Medical	291,394	297,285	319,145	296,359	283,396	303,867	275,925	36.9%
Fields	52,392	25,093	32,612	47,701	50,931	93,700	38,663	6.1%
West	0	0	0	0	0	17,815	28,027	0.8%

It is interesting to note that despite the physical expansion of the University, inter-annual water consumption is so variable that additions to Yale's physical space do not appear to correlate to proportional increases in water consumption, as should be made clear in Figure 5.

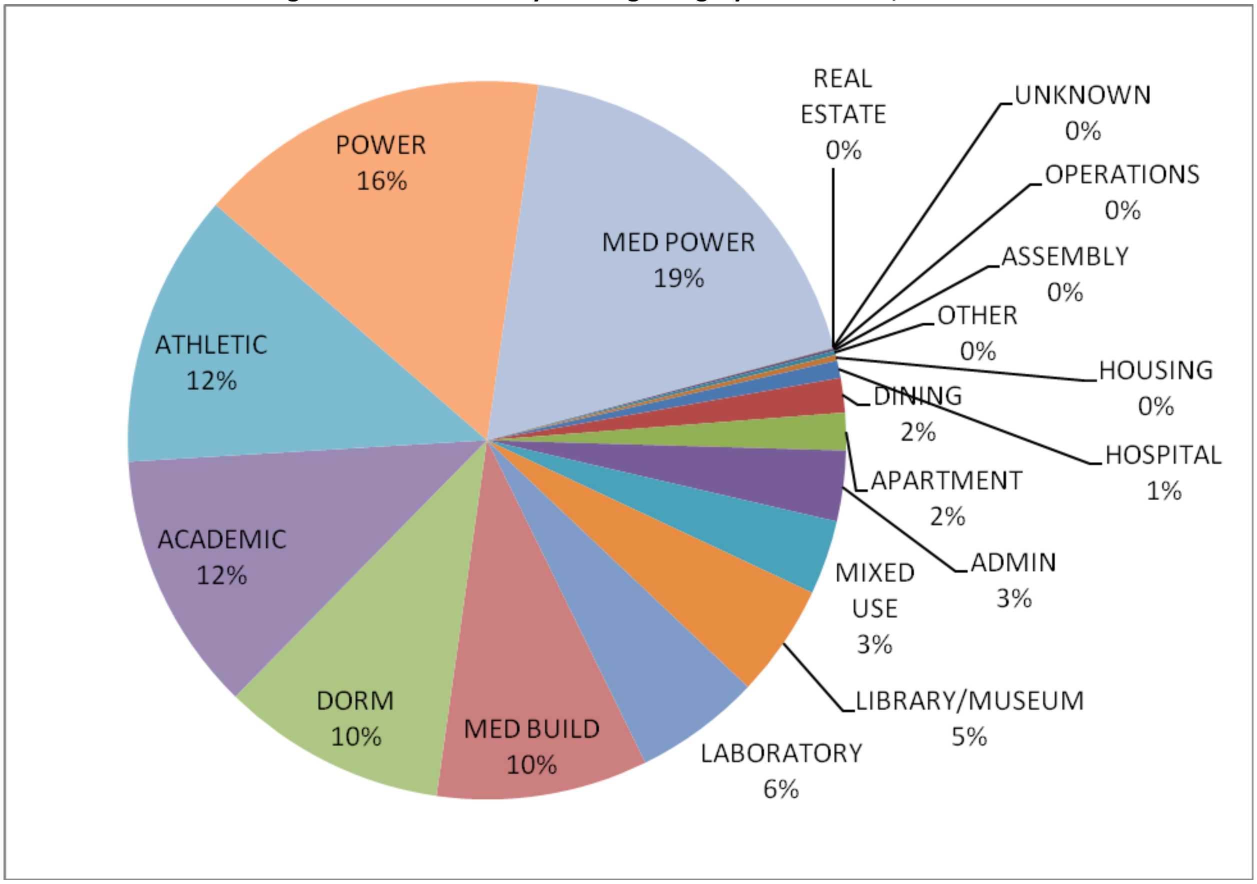
Figure 4 - Total annual adjusted consumption per fiscal year. Totals are divided by campus area



CATEGORICAL TOTALS

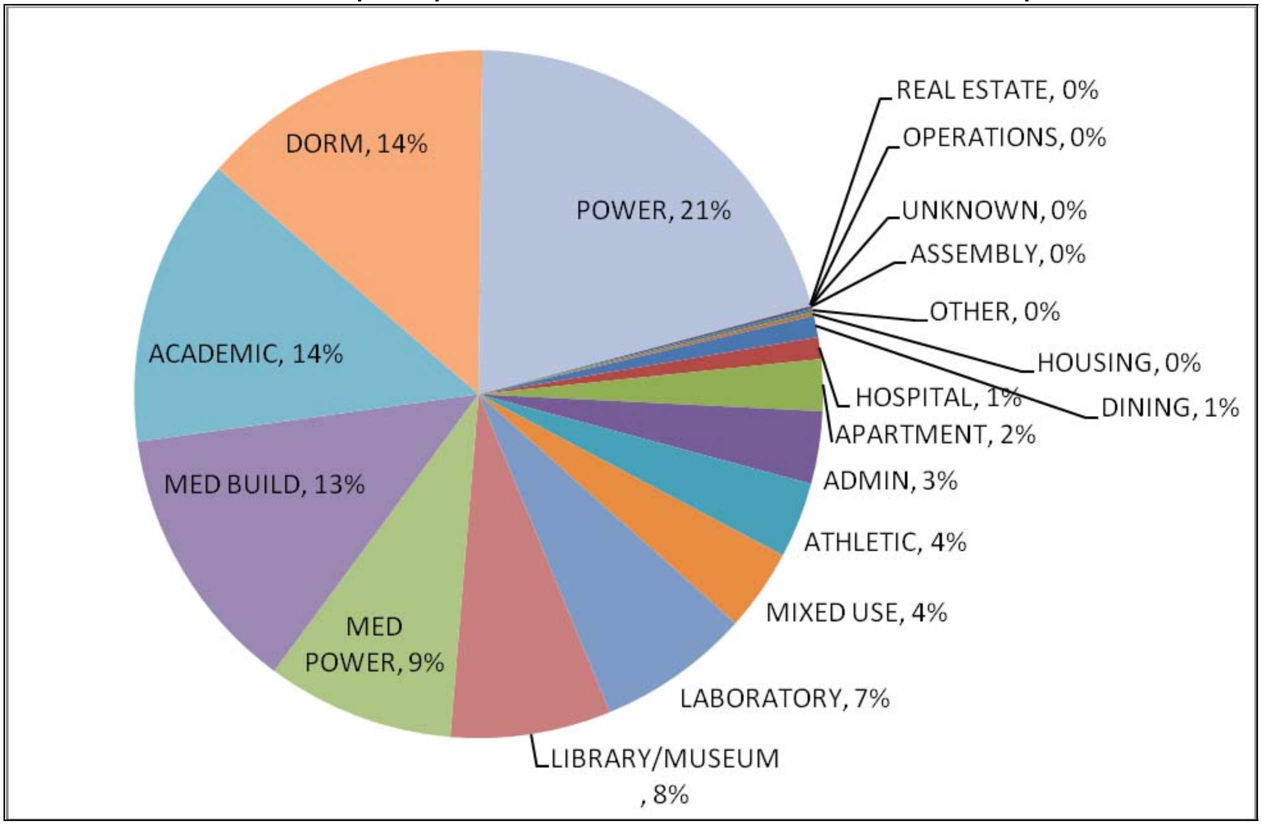
Analysis of categorical totals revealed that, as expected, the largest direct water consumers on campus are the power plants. For FY 2008, the percentage was 35% for the adjusted data. After the power plants, the largest categories of consumers were, on an annual basis: academic buildings (12% for FY 2008); athletic fields and recreational facilities (12%); dormitories (10%); laboratories (6%); and libraries/museums (5%). All other categories were small enough that they represent less than 3% of total usage. The percentages for FY 2008 are displayed in Figure 6 below.

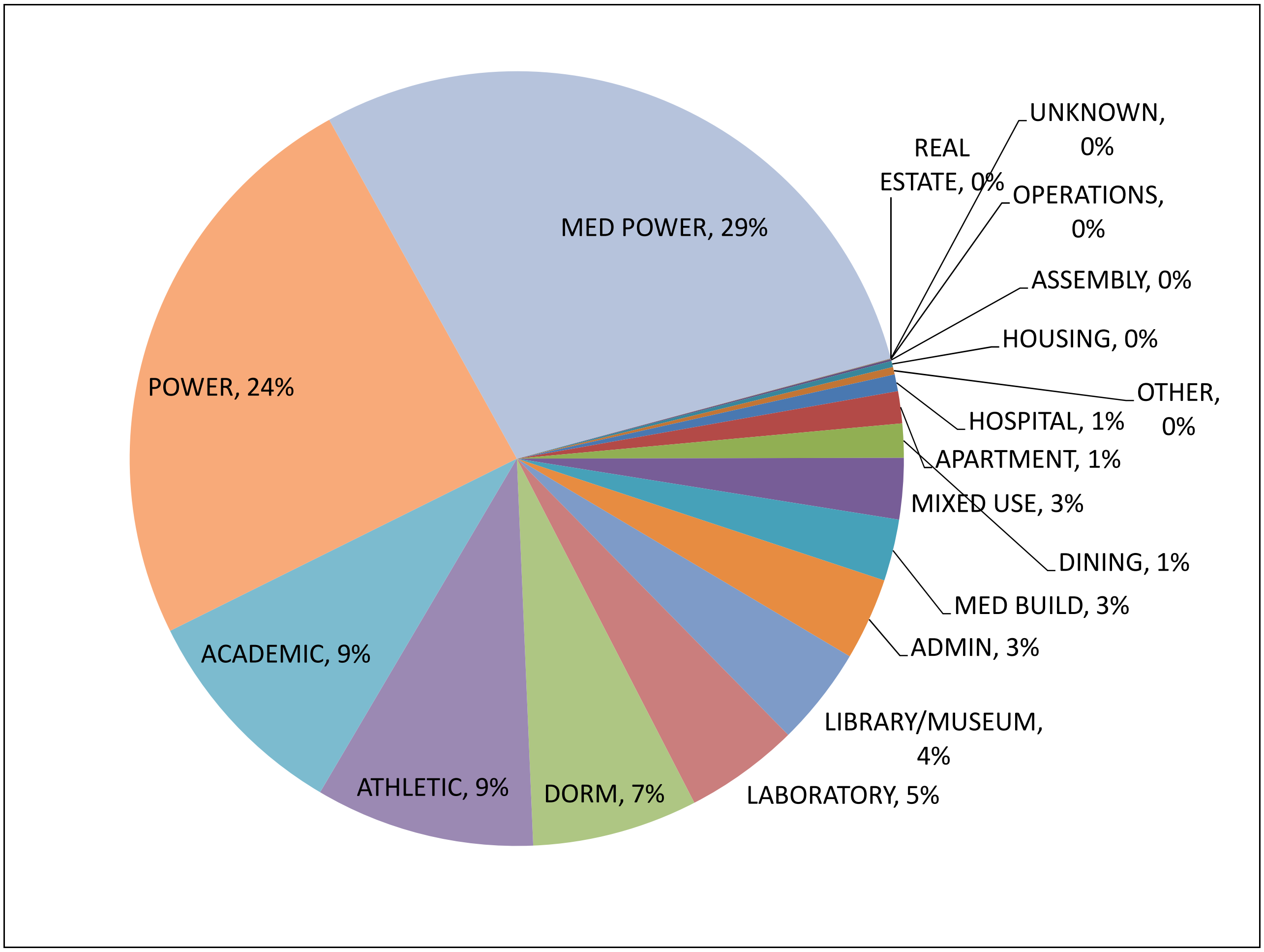
Figure 5 - FY 2008 Use by Building Category. Total = 837,531 CCF



It should be noted that these percentages come with two caveats. First, the “Med Build” category refers to the core Medical Campus, which is a collection of different types of buildings. This figure has not been disaggregated. Secondly, there are major changes in the percentages over quarters. For example, summers see a large increase in the water demands for power plants, and their consumption can increase to over 50%, resulting in relative decreases in the amount of water used by other categories. A comparison of winter and summer 2008 are displayed below in Figure 7. This means that a water-saving measure that is implemented on the basis of annual data might have a strong or weak effect on overall seasonal consumption, and vice-versa.

Figures 6 and 7 – 2008 winter (top) and summer (bottom) percentages of consumption by category. Consumption by the two main power plants fluctuates from 30% to 53% between the two quarters.





Finally, it appears as though the total amount of water consumed by different sectors is changing. Figure 8 below shows not only the relative sizes for the consumption amounts by each category, but also the annual change of those categories over the past seven fiscal years. There are evident decreases in some of the larger categories: Medical Campus water consumption, laboratory consumption, and dorm consumption all show clear decreasing trends. The calculated differences between FY 2009 and FY 2003 are displayed in Table 5. It is, however, possible that large parts of the decreases are explained by the “loss” of consumption due to the adjustments applied to deal with negative consumption.

Figure 6 - Water Consumption by Category, FY 2003 - FY 2009. FY 2003 is the back of the graph. Clear decreases in some of larger categories can be seen; however, areas such as "Power" are increasing. "Med Power" and "Med Build" are the disaggregated totals for the "Med Core" category; they are not available for years before FY 2007.

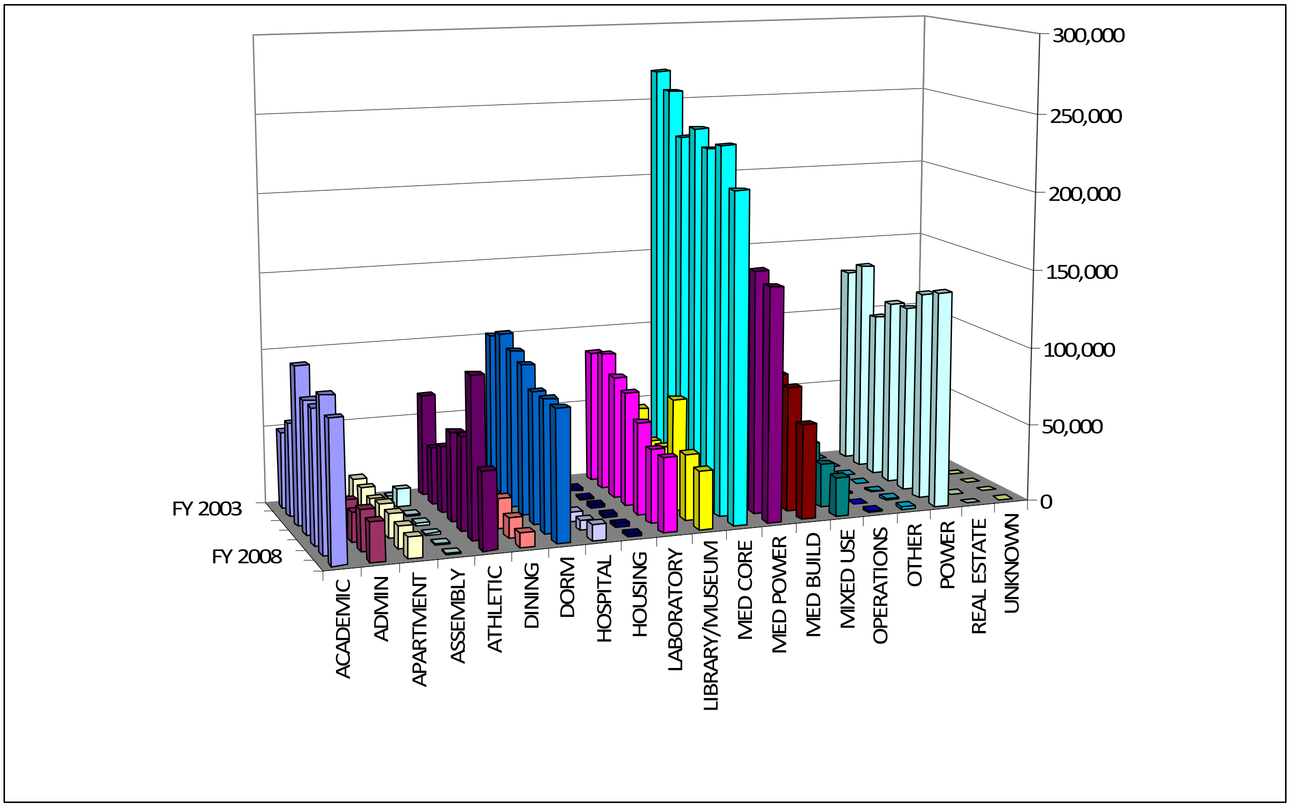


Table 4 - Change in consumption by category, FY 2003 - 2009

Category	Change CCF		
Academic	39895	Assembly	-277
Library/Museum	10686	Housing	-608
Administrative	10046	Apartment	-1035
Power	9929	Mixed Use	-3072
Other	1540	Dining	-3100
Operations	1199	Athletic	-16231
Hospital	991	Dormitory	-17420
Real Estate	-36	Laboratory	-37765
Unknown	-98	Med Core	-59720
		TOTAL	**-65076**

WATER CONSUMPTION PER SQUARE FOOT PER YEAR

In general, water use consumption per square foot of building floor space per year appears to have increased from FY 2003 through FY 2007, and then declined from FY 2008 through FY 2009 for the selected categories. Standard deviations across all years for the categories reveal that data for operations buildings and assembly buildings are highly distorted due to few data points and the presence of a few outliers for several buildings; this suggests that buildings in these categories are too few to obtain a meaningful or practically applicable average value for usage. Averages of other categories of buildings, however, show relatively narrow deviations from year to year, suggesting that average consumption per square foot of building space might be used as an indicator for these categories. It should be noted that this analysis is only applicable to building categories, not individual buildings. The summary is below in Table 6.

Additional caveats apply. It is again assumed that the decline in FY 2008 – 2009 is due to the proliferation of estimates and bad meter readings consumption over the last two years. Some of the averages are deceptively simple-looking; for example, there are only two "dining" buildings, Donaldson Commons and University Commons. University Commons regularly records an annual consumption rate of up to 230 gal / ft^2-yr, while Donaldson Commons rarely reaches 75 gal / ft^2-yr.

Table 5 - Average consumption per unit floor space, in gallons / ft^2-yr for selected building categories. Note that this is a subsample of all available buildings. The multi-year average and standard deviation of fiscal year totals is included.

Type	FY03	FY04	FY05	FY06	FY07	FY08	FY09	Average	σ
Academic	17.50	17.32	15.92	16.51	20.07	19.65	15.57	17.5	1.8
Administrative	21.45	18.81	18.04	26.79	32.27	20.31	14.59	21.8	5.9
Apartments	43.69	41.59	39.74	47.74	45.84	42.10	37.38	42.6	3.5
Assembly	6.93	64.38	6.08	10.20	7.06	6.29	4.82	15.1	21.8
Athletic Build.	17.71	22.28	15.89	14.19	13.65	15.38	11.63	15.8	3.4
Dining	103.88	114.78	117.26	125.18	139.89	106.28	87.36	113.5	16.7
Dormitory	34.75	38.22	39.59	34.35	31.20	28.62	27.20	33.4	4.7
Housing	21.82	18.03	12.19	19.88	23.42	24.34	19.39	19.9	4.1
Laboratory	68.93	67.76	60.27	56.29	43.03	32.60	30.07	51.3	16.1
Library/Muse.	11.40	29.21	15.07	17.58	25.31	19.17	16.11	19.1	6.2
Mixed Use	70.56	69.20	105.00	80.78	85.25	63.05	61.00	76.4	15.4
Operations	13.89	12.14	12.93	16.53	100.66	4.20	34.92	27.9	33.4

Breakdowns of water consumption for each of the buildings used to calculate four categories—administration, dormitories, laboratories, and administrative buildings—are displayed in Appendix A.

PER-STUDENT CONSUMPTION FOR THE RESIDENTIAL COLLEGES

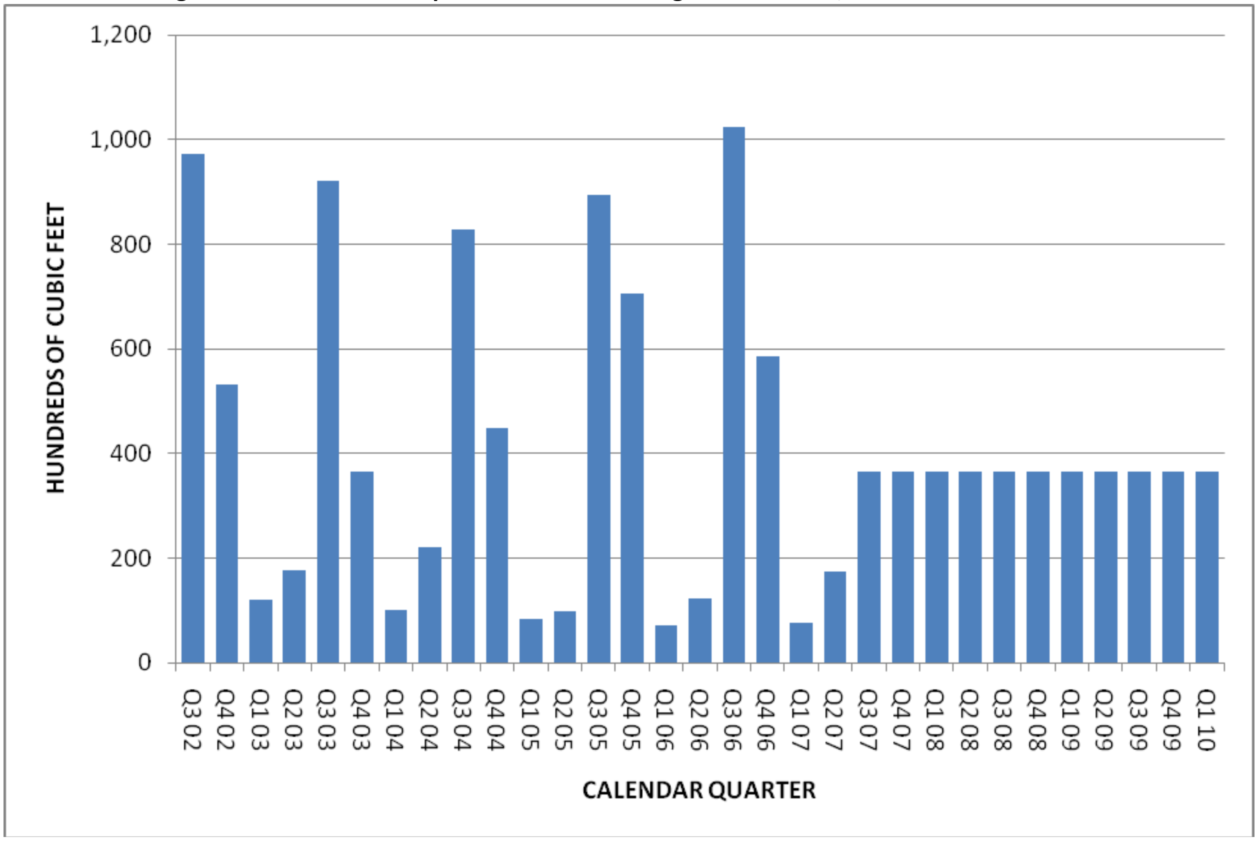
Averages of all quarters for each of the colleges ranged from a low of 2,966 gal/person for the Swing Dorm to a high of 7,678 gal/person for Berkeley College. Standard deviations for each row of data were large, beginning at 22% of the calculated average (for Ezra Stiles College) and reaching up to 60% (for the Swing Dorm). The high variability is likely due to the inaccuracies introduced by faulty meters and by attempts at adjusting the data. Interestingly, in almost all cases where a building was renovated during this time period, quarterly usage decreased for the years after the renovation. This suggests that refurbishment has had a positive effect in reducing water consumption intensity. This could be due to the replacement or upgrading of fixtures and pipes with new or improved equipment. However, as the last two years of consumption data are likely inaccurate, until future use consumption rates can be established via accurate consumption data, remains uncertain.

CASE STUDIES

1: METERS TO MULTIPLE BUILDINGS

The meter labeled WA-RWA-1070-001 is assigned to Sage-Bowers Hall. Graphs of quarterly quarterly water usage for that building revealed a pattern of abnormally high water consumption for the summer quarter of each year (Figure 9). Water use would reach up to 900 CCF from the end of May through the end of August, despite being as low as 50 CCF for preceding quarters. Sage Hall is an academic building, so it is used least during summer. Initially, it was assumed assumed that the building was using water for irrigation or for an unverified chilled-water cooling system. However, Sage is not connected to any irrigation systems, and and uses window-mounted electric air conditioning units. On-site examination revealed that the building has no cutoff valve between the building and the water main. (A cutoff is the valve along the lateral that runs from the main to the serviced building. It is attached to the lateral, accessible through a small hole in the street or sidewalk, and allows water service to be shut off; the caps are typically spray-painted blue for construction workers.)

Figure 7 – Water consumption attributed to Sage-Bowers Hall, summer 2002 – winter 2010

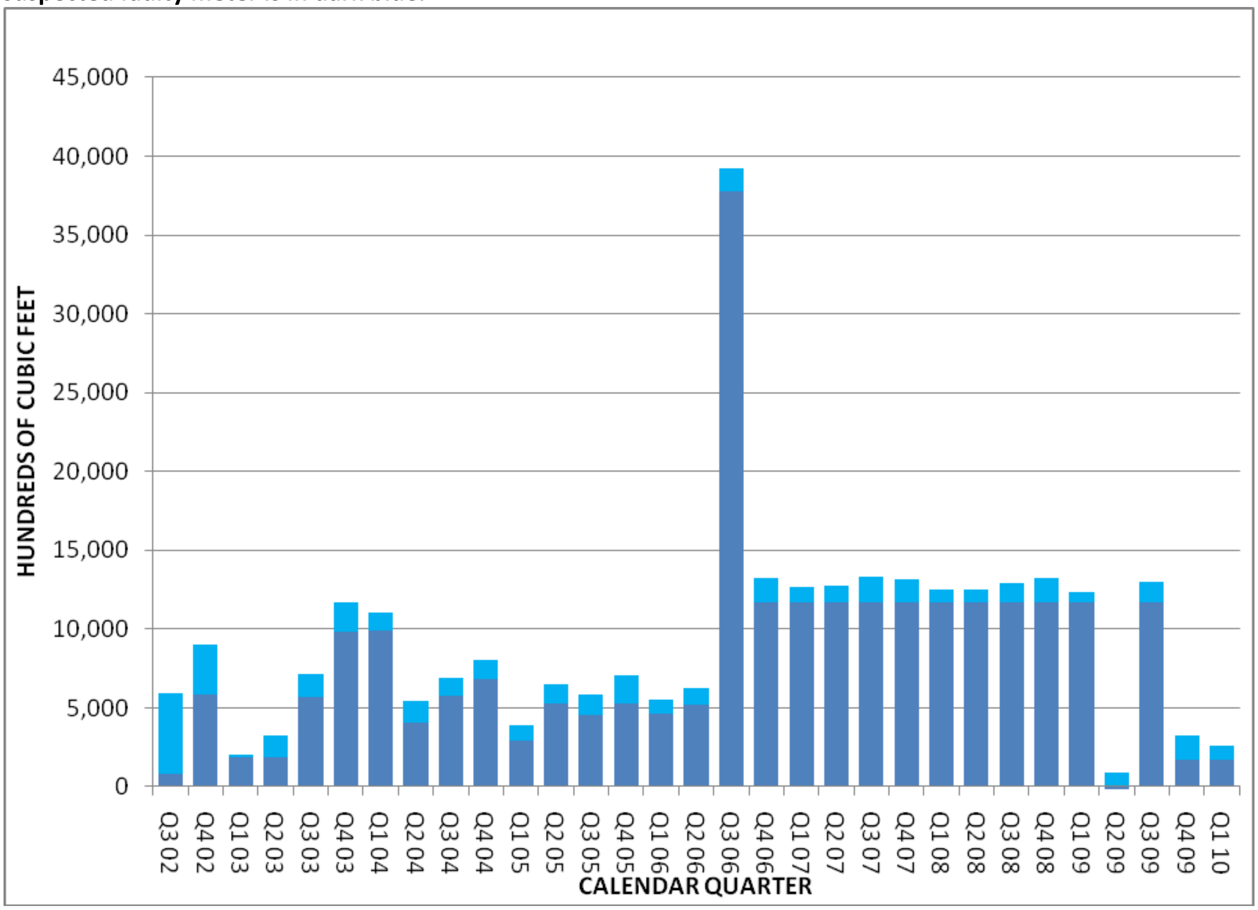


University utility maps confirmed that there was no lateral running from the water main to Sage Hall, nor were there any other apparent connections on its grounds. Water was likely coming from a pipe attached to another building. The Pierson-Sage Power Substation, as well as an underground refridgeration plant, were immediately adjacent to Sage Hall before construction on Kroon Hall began. This plant and the refridgeration facility have been replaced with the Science Hill Southwest Service Node. On-site visual inspection confirmed that Sage Hall is connected to the same meter that feeds the new service node. The same pipe system was almost certainly connected to the refrigeration plant. The two buildings had never been disaggregated.

2: PROBLEMS WITH ESTIMATES

Water consumption records for Sterling Memorial Library underline problems with the estimated values reported by the RWA. Estimates appear to be often based on averages of historical usage, but often that historical usage is itself distorted. The average from FY 2003 – 2006 of the two meters that feed SML was 6,596 CCF per quarter. At some point in summer 2006, one of the meters malfunctioned and registered over 30,000 CCF of water—about half of the consumption of the Central Power Plant for the same period. Afterwards, that meter's values were strictly estimates—however, the abnormally high value was included in the calculations for those estimates. Afterwards, Sterling Library had a billed consumption of an average of 50,000 CCF of water per year. More recent estimates have been lowered, but it seems as though the Regional Water Authority simply dropped the first digit of the value they had been using. This means that water use for SML for the past four years is highly inaccurate; Figure 10 shows all known usage.

Figure 8 – Quarterly combined water consumption for two meters attributed to Sterling Memorial Library from summer 2002 through winter 2010. One meter registered a huge spike in consumption in summer 2006; RWA estimated usage after this period was higher than it had been in any quarter previously. Consumption from the suspected faulty meter is in dark blue.



3: PROBLEMS WITH NEGATIVE NUMBERS

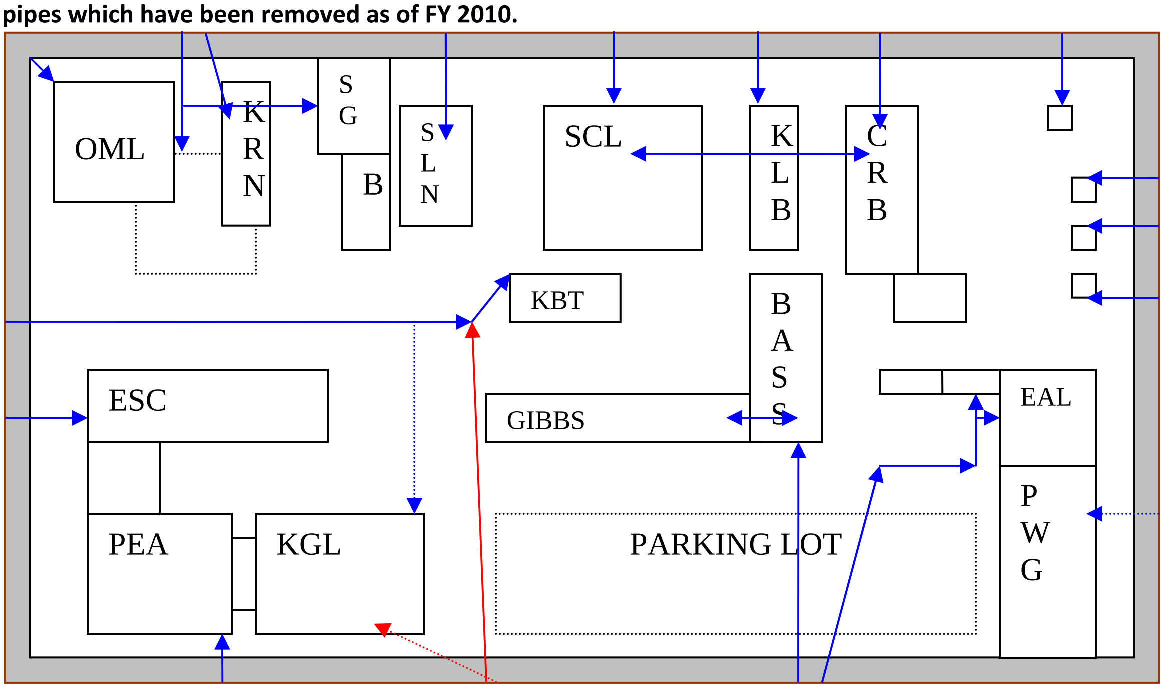
Meter WA-RWA-2630-001 is believed to be connected to Connecticut Hall and Welch Hall, two average-sized academic buildings in the Old Campus. From FY 2003 – 2006, water usage for this meter averaged 965 CCF per quarter. In the second quarter of FY 2007, usage shot up to 12,830 CCF, indicating a likely meter malfunction. The following quarter saw a credited amount, represented as negative water usage, that was vastly higher than the usage for the previous quarter, at -51,543 CCF. This was followed by consumption for the third quarter at 30,898 CCF. For the three quarters, the total recorded usage was -7815 CCF.

Investigation of original combined statements revealed that the meter in question had been replaced as of 3/13/2007. The original meter gave an inaccurate reading starting in at least the fourth quarter of 2006 and was credited for an overestimate in the first quarter of 2007. Water use for the second quarter of 2007 was a combination of the reading from the defective meter, which read 30,093 CCF from 3/01/2007 through 3/13/2007, and the replacement, which read 805 CCF from 3/13 through 5/21/2007. After this, the meter reported realistic usage values for two quarters, until again reporting estimates for all of 2008; these estimates were based on historical averages which unfortunately included the 30,898 figure. This overestimate was later credited for -33,678 in FQ1 2010 (summer 2009).

It should be pointed out that innaccuracy on this level, although eventually rectified, causes problems in addition to distortion of water use metrics. In particular, bad water meters also cause bad sewage charges. Sewage rates are not measured directly; they are instead based on readings from the RWA meters. For the meter above, periods of high use were not credited by the WPCA for reasons that are not understood.

4: LARGE SCALE INACCURACIES

Figure 11 – Science Hill Water Pipe Schematic. Whitney Avenue is at the bottom of the figure. Red lines represent pipes which have been removed as of FY 2010.



From summer 2002 through winter 2009, E-CAP queries and combined statements showed that Kline Geology Laboratory used an avaerage of 2500 CCF per quarter. While that amount is not exceptional for a laboratory building, RWA statements indicated the meter was for an 8" pipe, a size usually reserved for water mains that deliver to power-plant-sized facilities. The actual site of the meter itself—as indicated by the cement box and transponder access port visible on Whitney Avenue—is next to KGL, but the location of the pipe was uncertain.

A recent on-site inspection provided some clarity. Kline Geology Laboratory has been under renovation for the past year. The author met with Mr. Jerry Gonsalves, the lead plumber for Harry

Grodsky & Company, Inc., one of the mechanical installation contractors for KGL . Mr. Gonsalves explained that an 8” main formerly ran east-west through the KGL basement and up into Science Hill. KGL itself was supplied by a 4” lateral from this main. The lateral was attached to an internal meter which, in his estimation, had not been checked for many years. He showed that the 8” main, the 4” lateral and all water meters have been removed, and that the current feed to KGL is now coming from other Yale infrastructure on the east side of the building.

Data from E-CAP have shown that the account in question was deleted as of spring 2009. Subsurface utility maps from the Yale Plan Room revealed the existance of the 8” main as of 2007. A 4” lateral to KGL from the city water main under Whitney Avenue was also present at that time, although it is unknown whether this was the meter from which service was drawn. The 8” main also ran uphill and intersected with two other water mains; these are believed to be WA-RWA-1065-002, the main supply pipe for Kline Biology Tower. The existing connection to KGL now comes from a new meter somewhere on Sachem Street. There is also evidence that a back-up pipe coming from the former underground refridgeration plant underneath what is now Kroon Hall was also contributing water to both Kline buildings.

This means that the meter that is associated with KGL, in fact, has been serving multiple buildings for the entire period of record; Kline Biology Tower’s water use intensity is highly underestimated, while KGL’s is highly overestimated. Existing data and calculations are inaccurate. Furthermore, although it is now possible that the both buildings are fed by a single replacement metered account, new information was not available by the time of this report.

RECOMMENDATIONS

RECOMMENDATION 1: IMPROVE DATA GATHERING

Yale University cannot make informed decisions about water conservation without good information. At present, water data for many of the largest buildings in the campus is incomplete at best and inaccurate at worst.

A. Begin Internal Monitoring of Water Consumption. For whatever reason, the RWA cannot provide accurate data for many of the largest meters on campus. Although it is able to eventually detect errors or overcharges and credit them to Yale’s accounts, the credits distort measured amounts of real water use for multiple quarters, or in some cases years. Because sewage charges are based on water meter readings—there are, thankfully, no “sewer meters”—many of the sewage use values billed to Yale are similarly distorted. Although replacement of many of the defective meters is currently underway, it is unknown how quickly the RWA will be able to respond to meter breakdowns in the future. Yale would greatly benefit by monitoring its own water consumption.

Internal water meters have been described as cheap, but the combination of installation costs, maintenance, service interruptions, and future replacement costs might be prohibitive. It is therefore recommended that, once cost constraints are calculated, a threshold for meter installation be set; the goal would be to install meters on Yale’s larger water consumers based on annual consumption. For example, an estimated annual average use of at least 1000 CCF could be the threshold; this would mean monitoring large buildings such as the University Commons, the Residential Colleges, or the individual Medical Campus halls, but relying upon RWA estimates for smaller buildings like 301 Prospect Street.

If meter installation is cost-prohibitive, a plausible alternative would be to purchase a set of external meters, as are used in Sterling Power Plant. These measure flow rates using ultrasonic sound emitters, and are attached to a pipe, but do not interrupt actual flow. These could be rotated through different buildings at different times. Internal metering would also allow for monitoring water use over periods of time that are more conducive towards Yale's fiscal operations; for example, the "January" water bill, paid for the third fiscal quarter of the year, actually represents water usage from the middle of November through the end of February.

B. Meter Large Buildings Individually
At present, Kline Geology Laboratory is attached to the same meter (or meters) that feed Kline Biology Tower and possibly other buildings. This means that usages for the individual buildings have to be based off estimates, which introduces additional uncertainty into calculations. Currently, different buildings that are attached to the same meter are disaggregated by comparing the relative square footage of the two buildings. This method has serious disadvantages. A theater, for example, might be much larger than a laboratory building, but the theater will necessarily use less water than the laboratory. Not metering individual buildings prevents the detection of major leaks in underground pipes.

Note that the power plants, of course, are already monitored with highly accurate meters.

C. Develop a complete map of the University's Potable Water Infrastructure. Yale University has detailed maps for most of its utility distribution networks, but potable water is a glaring exception. There is, to the author's knowledge, no complete map of potable water pipes for the Central or Medical campuses, nor is there a map that shows connections between adjacent buildings. Some buildings are "off the grid." Furthermore, while there are utility maps that show all utility connections exist, many of them have not been updated, and others display pipes that exist but are not being used without differentiating.

D. Develop an alternative water monitoring regime. Installing meters or improving the quality of records will ultimately be useless if it is not monitored regularly over time. At the very least, many existing water meters can be read in the field by some combination of the members of the Yale community. If internal meters are installed, it is imperative that they are regularly recorded over defined date ranges. This is a simple data-collection task, but the large number of buildings will make it time-consuming.

RECOMMENDATION 2: GATHER ADDITIONAL TYPES OF DATA
A. Perform Comprehensive Water Audits. Yale's available water data are lacking. Even with improved reporting, it meter accuracy can be off in the range of thousands of gallons. An alternative to relying solely upon meter data is to perform a comprehensive water audit for most, or for the

most intensive, water users on campus. Water audits are commonly performed during any assessment of industrial of water consumption, as meters are often upstream of inefficient machinery or internal leaks. It is essential for determining what activities account for the majority of an individual building's water use. For example, what is the primary use of water in the Residential Colleges? Given only meter data, we do not know if it is due to student showering, restroom use, food preparation, or some other activity. Without this information, the University cannot make any targeted policies towards reducing the worst or most wasteful water consumption practices.

A complete water audit involves on-site inspection, counting, and flow-rate measurement of toilets, faucets, and other fixtures within a building, either in their entirety or as a statistically meaningful sub-sample. Irrigation system output must also be measured. Additional data, including the temperature of hot and cold water outputs, the presence of aerators on faucets or other specialized attachments, and purge volumes of hot water faucets can be recorded. Water auditing also determines the efficiency of installed plumbing fixtures: a low-flow toilet, if improperly installed or malfunctioning, can use much more water than its stated capacity. Leaks in heavier types of infrastructure are common; R. Jess Muir, Chief Engineer of Sterling Power Plant, estimated that the Medical Campus system lost 5 - 6% of its water (as a liquid or as steam).[2]

Water auditing also requires tabulation of use rates for each figure. These are often based on estimations of use; however, small water meters can be installed on many internal fixtures. This would greatly enhance end-use data. Collecting audit information would be a labor-intensive process, but it is not terribly complicated. An advantage possessed by the University is the presence of certain groups of enthusiastic students who are also undemanding in terms of wages.

B. Irrigation Systems. Yale's irrigation systems are an unknown variable. An interview with Phillip Sissick, Deputy Director for Facilities Operations, explained that Yale's irrigation systems are operated on an *ad hoc* basis; that is, individual Grounds personnel, building superintendents or even in some cases Residential College Masters operate the irrigation systems based on their own understanding of landscaping water requirements. Ironically, the systems, as they are engineered often put out too much water, risking asphyxiation of plant roots. Sissick also cautioned that irrigation systems are constantly degrading, and at a rate faster than that of above-ground water systems, as no one can see underground leaks in the system.[3]

Sissick also confirmed that no one seems to know which buildings all (approximately) 85 irrigation networks are connected to. An audit of irrigation systems, as well as the development of a protocol to estimate their output, should be completed. The irrigation systems should also be mapped out in some way.

RECOMMENDATION 3: IMPROVE DATA REPORTING

[2] Personal Interview, 5 April 2010.

[3] Personal Interview, 29 April 2010.

A. Change the time period used for water use. At present, all water consumption data gathered by the Office of Facilities is reported as belonging to an arbitrary Fiscal Quarter. As described in the "Available Data" section, this practice means that as much as half of the water use reported in the FQ in question actually occurred *before* that fiscal quarter. As total quarterly consumption from the RWA cannot be disaggregated by day, week or even month, this practice must be ended. Indeed, the author is not certain if the charts above are totally clear, given this inconvenience. To improve this, water use should not be reported per fiscal quarter, but instead should be reported per billing period as described by RWA bills. Most of this data is already available, but is not used for the Energy Explorer or for many aggregations of annual water use in E-CAP queries.

B. Build an index of water use rates for individual buildings and provide the information to the buildings' occupants. Once improved data become available, provide this data to building residents. Many envision a "water war" between Residential Colleges, where the students compete to use the least water over a given period, via student-friendly conservation measures such as avoiding dining-hall tray use or avoiding showering. This is only possible with accurate monitoring.

C. Flag malfunctioning fixtures to building residents and appropriate maintenance authorities. If fixtures are broken or are not functioning properly, building residents should be informed, as should maintenance staff.