UNIVERSITY OF CALIFORNIA
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Methodology For Surveying And Analyzing Water Use In UCLA Research And Teaching Buildings

A thesis submitted in partial satisfaction of the
requirements for the degree Master of Science in Civil
Engineering

By

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Professor Michael K. Stenstrom, Chair

UCLA Facilities Management has an on going program to conserve the use of water on campus. This includes water used for irrigation, heating ventilation and cooling (HVAC), sanitary disposal, equipment cooling and a myriad of other purposes. Except for irrigation, a high proportion of each of these uses takes place inside

buildings. The purpose of this report is to provide a methodology for studying this use and a way of evaluating potential benefits from conservation.

The fundamental approach that is used in this report is conservation of mass: the amount of water coming into a building equals the amount that comes out. The report gives instructions on how to inspect a site and make measurements. The function of various major building systems is also explained with reference to how they consume water. Finally, a method for analyzing the collected data and identifying areas where efforts to conserve water are financially justified is presented.

During the preparation of this report a survey of water use at the Molecular Biology Institute (MBI) was performed as a case study. The methodology and results of this survey are given as an illustration of the concepts presented.

The conclusion of this analysis is that a thorough understanding of the various uses of water in campus buildings can lead to significant water conservation opportunities. This understanding includes not only how water is used but the quality and chemistry of the water as well. In addition to traditional methods to minimize usage, water reuse systems offer significant potential for conservation.

1) Introduction

1a) Purpose of Analysis

The purpose of this analysis is to provide a methodology for identifying campus building water use. The focus will be on how to gather data to determine water use in a research and or teaching building and how to analyze the costs involved in reducing that usage (if any such opportunities exist). Other types of buildings will require modifications to the methods presented here.

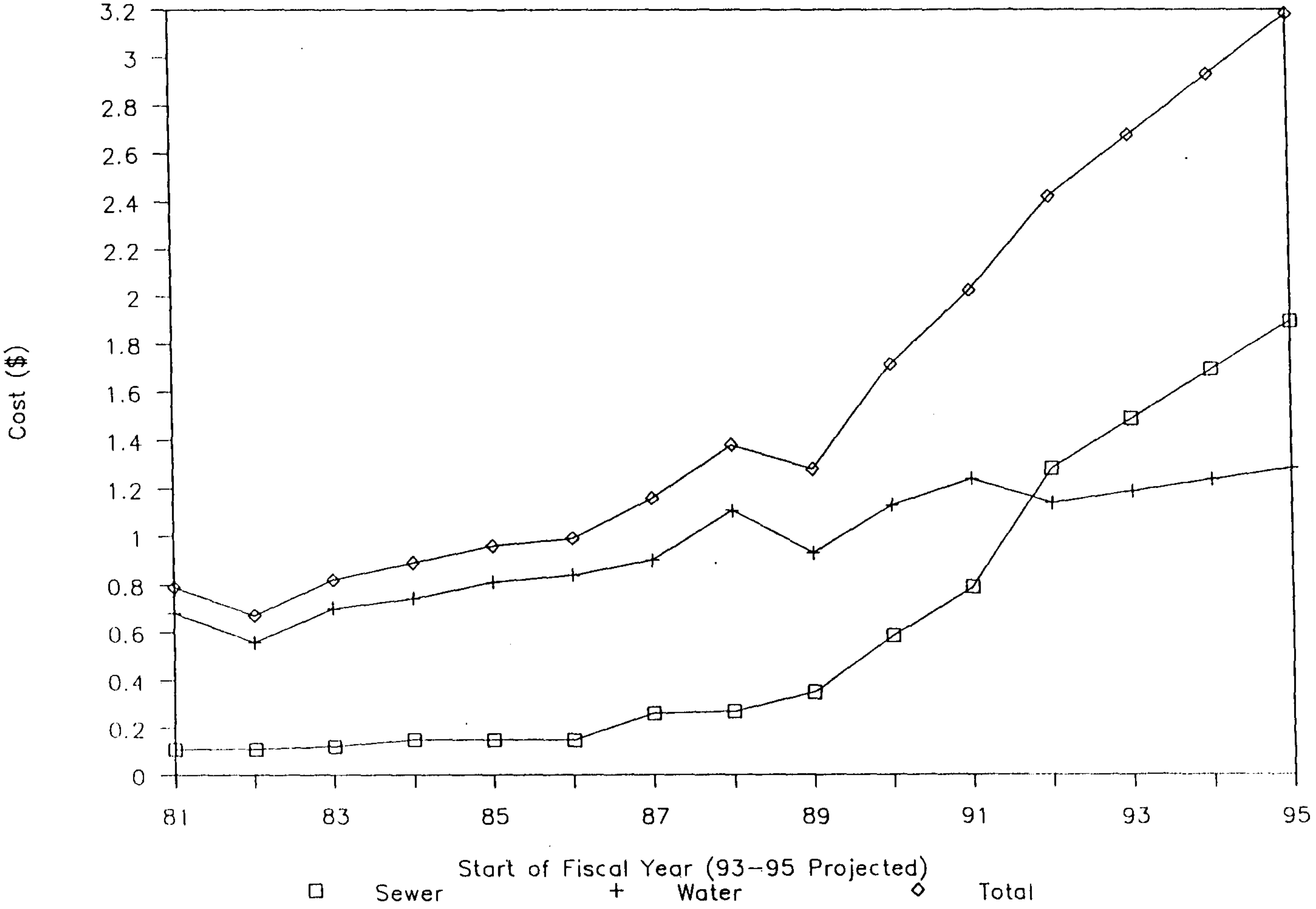
Most of the examples in this report will be drawn from a study that was conducted on the Molecular Biology Institute (MBI) building (also known as Life Sciences III). MBI is a research building, but teaching buildings have many of the same water uses. The results of this analysis can be extrapolated to academic buildings using the methods provided.

1b) Cost and Usage Factors

Cost and usage increases have several components. Figure 1 shows that the purchase price of water between the years 1981 to 1992 rose about 67% or about 6.1% per year in a roughly linear fashion. However, over the same time period sewerage costs have shown quite a different trend.

Fig. 1 Water Purchase and Disposal Cost

(Dollars Per Hundred Cubic Feet)

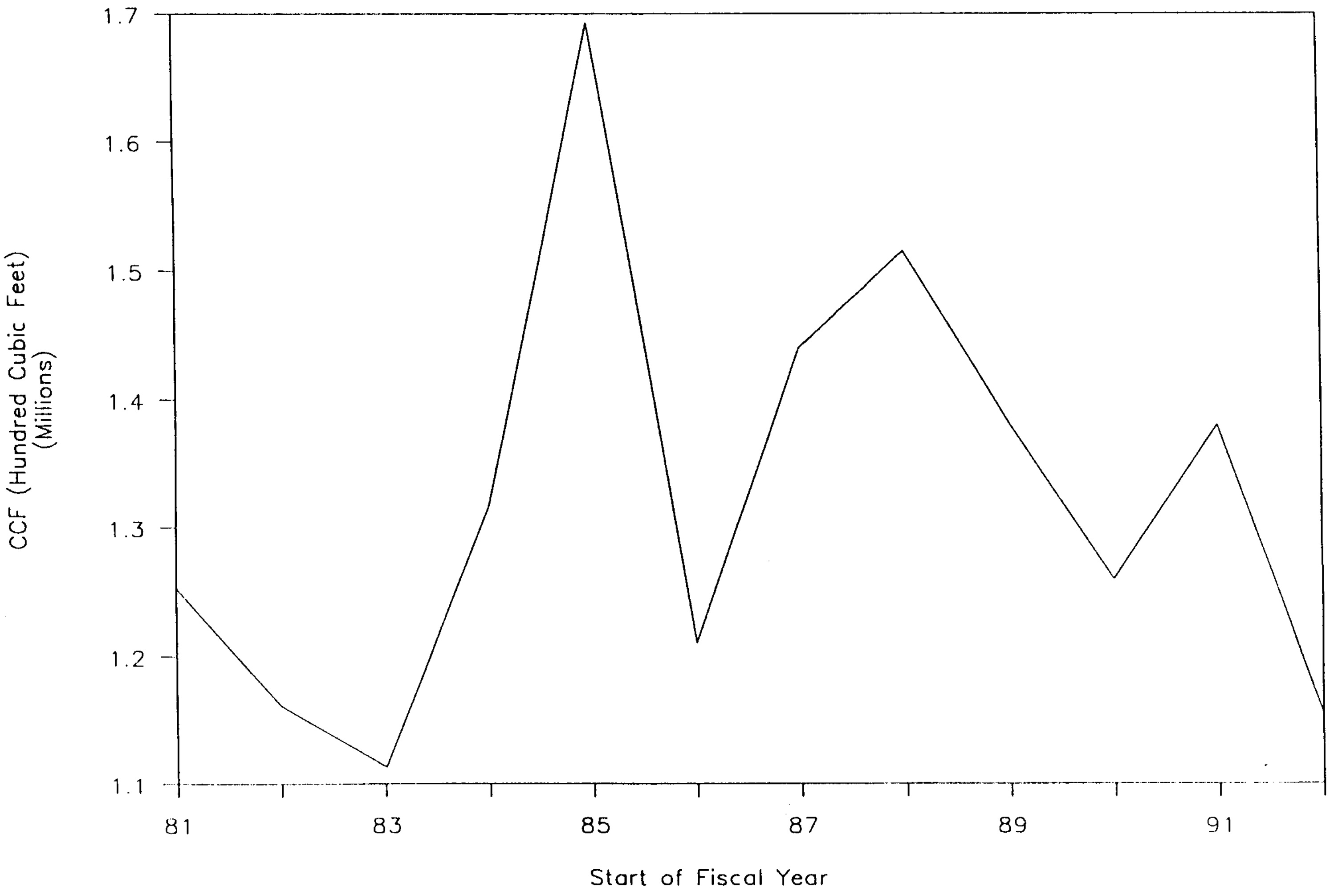


Sewerage costs have been increasing rapidly, especially in the last five years. Figure 1 shows that since 1981, sewerage costs increased 1211% with a 368% increase in the last four years alone. In 1992, for the first time, it actually cost more to dispose of the water than to purchase it! As shown in Figure 1, the total cost for purchase and disposal of one hundred cubic feet (CCF) of water was $2.43 in 1992 (or $1,058.51/acre-ft). Assuming the average increase in total cost over the last five years, about 25 cents/year, were to continue the total cost for water purchase and disposal would rise to about $3.18/CCF in 1995 (or $1,385.21/acre-ft).

These increases come from several factors. The City of Los Angeles is currently spending billions of dollars to upgrade the Hyperion sewage treatment facility because the elimination of ocean discharge of partially treated sewage has been mandated by federal law. Stringent new laws are redefining many types of wastes as toxic and greatly restricting their allowable concentrations in the waste stream. These costs are passed on in the form of higher sewerage fees.

Total water usage at UCLA in the year 1991-1992 was 1,154,843 CCF (hundred cubic feet). Figure 2 shows that

Fig. 2 UCLA Campus Water Use



water usage at UCLA peaked in 1985 and has since decreased. This decrease took place despite the addition of 6,768,906 square feet of maintained campus space (Fig.3). The current trend in water use is downward but there is considerable year to year variability owing primarily to weather influences. This downward trend indicates the success of the UCLA water conservation effort.

1c) Campus Water Use Categories

Figure 4 shows that in 1991 it was estimated that 50% of campus water consumption went to heating ventilating and cooling (HVAC), 18% to hygienic purposes such as lavatories, 16% to irrigation and 16% to other purposes (water cooled equipment, etc). Reductions in water use for irrigation are currently being addressed by an on going program initiated in fiscal year 1985-86. It is estimated that this program to replace older galvanized pipe with plastic (PVC), install electronic controllers and more efficient irrigation heads has already reduced campus water use by 16,040 CCF/Yr. Because of the success of this program, conservation issues involving

Fig. 3 Maintained Gross Square Feet

(Campus Building Space)

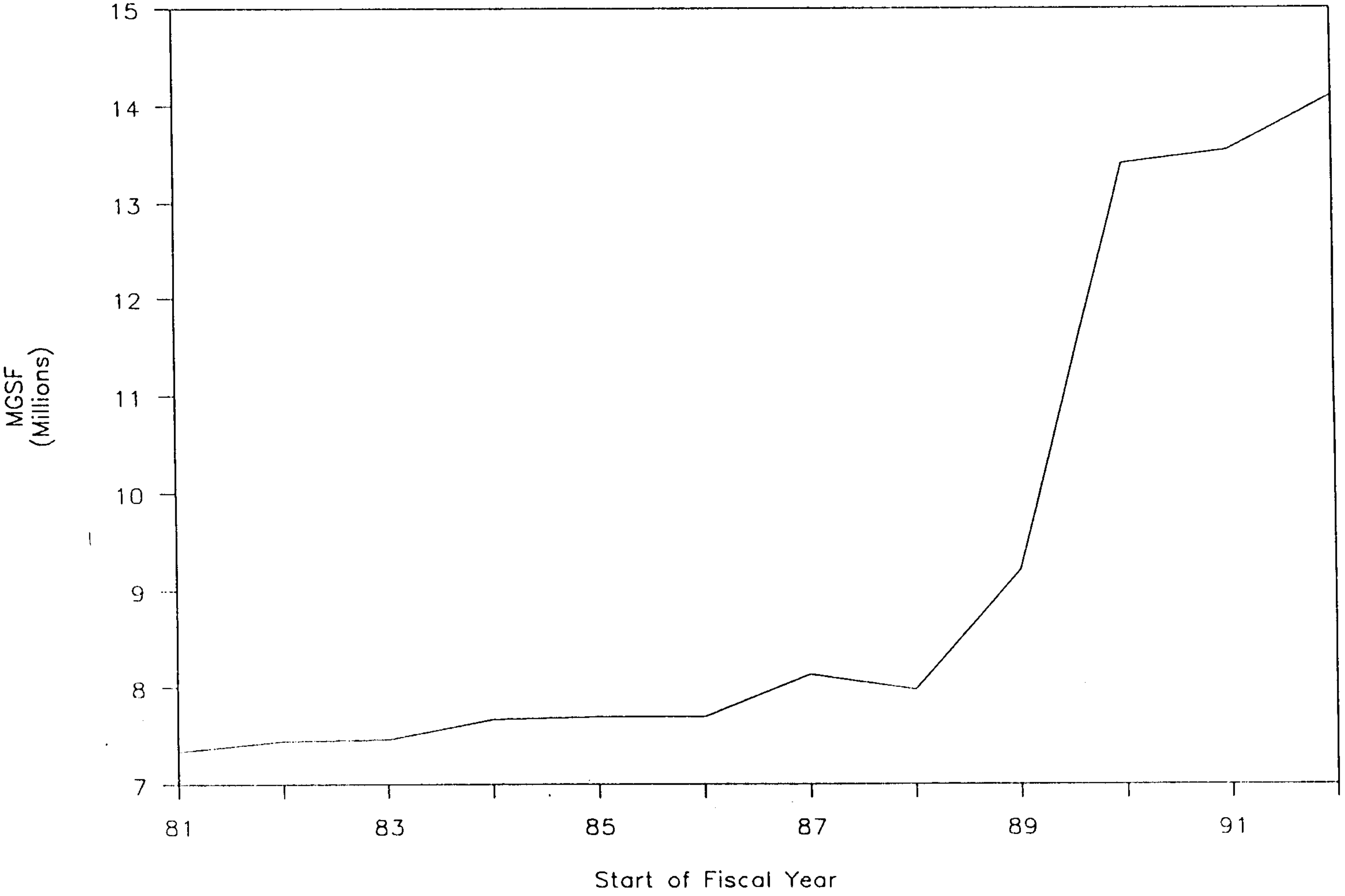
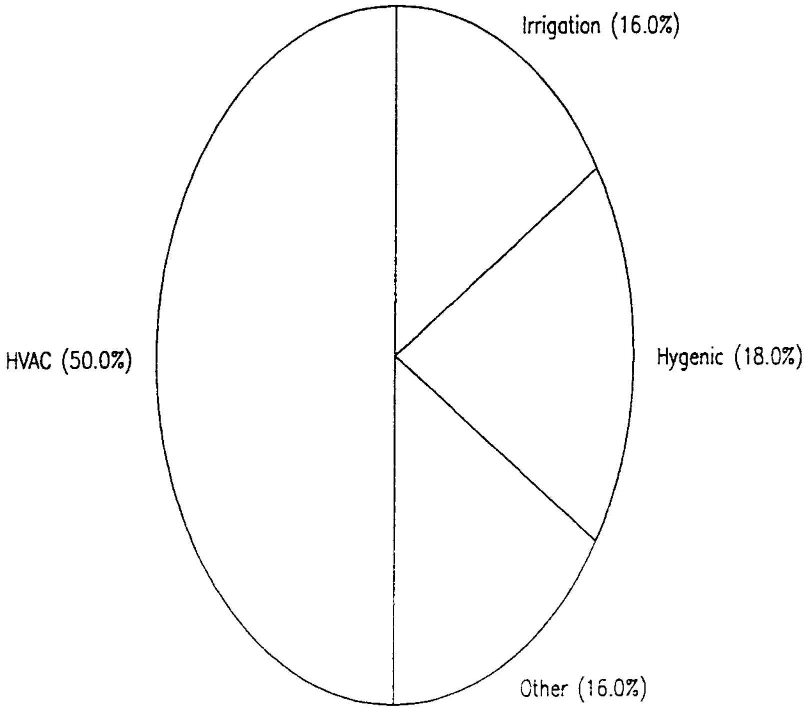


Fig 4. UCLA Water Consumption

By Category (1991)



irrigation are not addressed in this report. Almost all of the remaining 84% of water use takes place inside buildings.

1d) Analysis Approach

The fundamental approach taken here is mass balance. The total amount of water flowing into a building must equal the total outflows (including losses to the atmosphere from cooling towers). Inflows to the building include potable water from city mains (city water) and "shared" water from nearby buildings. Shared water is water that flows from one building to another rather than from the outside water mains. Storm drain outlets and piping are segregated from the sewage outlets and piping and so are not part of the mass balance. Outflows from the building are such things as: sewage drains, shared water flowing from the building in question to another building, evaporation from cooling towers and a small amount of drinking water that is actually consumed by humans and animals and that does not become a part of the sewage outflow.

One of the primary advantages of using the mass balance approach is that while most of the inflows are relatively easy to measure, some of the outflows can only be estimated or measured with great difficulty. By subtracting the major outflows that are known from the total inflow the remainder must equal the sum of the difficult to measure outflows. This means that in many cases the difficult measurements can be avoided. However, there are certain drawbacks to this method which will be discussed latter.

2) Data Gathering

Data gathering is one of the most important and time consuming steps in performing a water use study. Without proper attention to data gathering the analysis will lead to wrong conclusions about where to spend the available time and money.

2a) Building Drawings and Space Inventory

Construction ("As Built") drawings for all UCLA buildings are located in the Capital Programs plan room. The ones of primary interest to the investigator are the plumbing and HVAC. These drawings contain information on how a building's various systems were originally intended to work and most major remodeling changes. Careful examination of the drawings should reveal the location of many of the major water using components of the building such as cooling towers, water purification plants, vacuum pumps, city water inlets, water meters, sewage outlets and building systems like water cooled condensers for refrigerators. These locations provide a starting point for the on site inspection.

UCLA's Insite 3 Space Facilities Inventory database provides, among other things, the room numbers, square footage, room type and number of work stations for each building. These "work stations" are an inventory device for counting the number of people that normally occupy a room as their primary work location. This information is mainly used during the analysis phase of the study. However, the room type and square footage information can also be used during the preliminary phase of an investigation when deciding which building(s) should be studied and how much study time to allocate. For instance, a study of a building that is large but is mostly classrooms would go quickly since most of the rooms have no individual water consumption. A building that is medium size but consists mostly of labs might take much longer since labs tend to customize water usage to their particular needs.

2b) Building Personnel

The personnel resources typically available to provide information on a building's water using systems are: the Building Manager, Facilities Management personnel and the building occupants. One reason the Manager and the Facilities Management Personnel are important is that UCLA does not have a document control system that continuously updates building drawings. This means that a building will sometimes have systems that are significantly different from the "As Built" drawings. The Building Manager and Facilities Management personnel such as the Assistant Chief Engineer will often have information about these undocumented changes to the building's design. This information makes it easier for the investigator to understand the function of these changes without having to resort to time consuming pipe tracing.

Facilities Management craftspeople are responsible for operating building processes such as cooling towers and process refrigeration. The Investigator should contact these craftspeople to find out how these processes are being controlled and any operating problems that have been encountered in the past.

Another good reason for consulting with Facilities craftspeople is that they will ultimately be responsible for maintaining many of the conservation practices the study recommends. Since it is their job to operate the building, they should have some input in any discussion of changes in the way the building is routinely run. Also, their experience can be used to improve on any proposed changes.

Craftspeople can give good advice on ways to cut costs, estimate construction times and decide whether something will fit into a given space. Having the assistance of a craftsperson can also add a reality check to a proposal.

Building occupants know little of how a building is operated as a whole and the investigator should not automatically accept the information that they provide. Many times lab residents think that their equipment recycles water when ultimately it does not. This is because occupants often do not understand that a recycling loop in one area may be connected to a non-recycling loop in another through some type of heat exchanger. Nevertheless, occupants should still be consulted because they might be able to provide valuable information about the water usage aspects of a specific piece of equipment or process.

2c) Site Inspection

The main goal of the site inspection is to identify locations where measurement must be made. With this in

Fig.5

Water Usage Survey Sheet

Date:
Page:

Investigator:	Bldg:	Contact Person(s) / Title(s) / Phone#(s):

Rm#:	Rm Code:	Instrument or Process:	Max GPD:	Factor of Use:	Notes:

mind the investigator should walk each of the building's floors. Using a survey sheet, as shown in Figure 5, the investigator must identify and record the available data on equipment that uses a significant amount of water. Equipment identification requires that the investigator look at the connections (usually in back against the wall) of suspected water using equipment. Typical equipment of interest would be electron microscopes, centrifuges, autoclaves, fermenters, reverse osmosis units, walk in refrigerators and vacuum pumps. Care must be taken to inspect pipe connections thoroughly because a few of these devices will turn out to be air cooled and so have no water use. For equipment that is provided with built in flow meters the meter readings should be recorded.

The next step in the inspection is to compare the drawings of the major building systems such as water towers and the city water inlet(s) with the actual installation. Sometimes these have been altered over the years. A clear understanding of how these systems actually work is necessary so that measurements of their water consumption will be correct. For example, a second water line from another building is sometimes added to science buildings as a back up system to the primary line. In some cases these lines are kept shut off and so would not change the building's normal operation. In others they operate continuously as a second water supply.

2d) On-Site Measurements

After the sites where measurements and observations need to be made have been determined, data collection can begin. Three basic types of water flow data collection can be used: reading of existing meters, timed filling of graduated containers and ultra-sonic flow meters. However, before these can be described a discussion on data collection accuracy and filling out the survey sheets is appropriate.

It is important to balance data gathering accuracy with the cost in time necessary to obtain that level of accuracy. For example, an error of 10% on a cooling tower that uses 100,000 gallons per day is 10,000 gallons, a large amount and well worth the extra time to get a very good measurement. On the other hand, a measurement on a centrifuge that uses 500 gallons per day could be off 10% and still not make a big change in a building's total water use. The objective is to collect data which will be accurate enough for decision making on potential conservation measures.

The data collected are to be entered on the Water Usage Survey Sheets (see Fig. 5) for eventual entry into the water usage database established for this report (See App. 8c). The various database items are fairly self explanatory except for Room Code, GPD and Factor of Use. Room Code indicates the use the room is being put to:

Lab	Class or research lab
Fac	Facilities equipment room
Cls	Classroom
Anq	Animal quarters
Grn	Green house
Off	Offices, conference rooms, other administrative spaces
Std	Study rooms
Lib	Library
Shp	Shop
Str	Storage
Otr	Other, many other types of rooms exist, add a short description in the notes column when this code is used

Max GPD is gallons per day that would be used if the device ran continuously. Factor of use is that fraction of an average twenty-four hour day that the device operates. The product of these two is the actual gallons used per day. This actual gallons per day is our decision making variable. Because of this it is completely acceptable to take average values for Max GPD and factor of use as long as the product comes out to the actual number of gallons that a piece of equipment typically uses.

The easiest way to collect flow data is to read any meters that are on the equipment. It is important to make certain that the meter is actually reading water flow that goes down the drain, not flow that recirculates in the equipment. The flow must be timed over a period of at least ten or fifteen minutes to see if it has more than one mode of operation. The duration and flow rate of each mode must be recorded. If the flow is highly variable then an approximate average must be taken. If the equipment is a relatively low flow device and is in operation consider this measurement adequate. If it has a large flow or has flow even when turned off, several measurements on different days would be better. The investigator needs to make a judgement call on this.

Most small and medium sized pieces of equipment do not have flow meters. Instead they dump directly into a floor drain. If the flow rate is small and the drain is deep, a graduated container may fit directly inside of the drain to measure the flow. Otherwise, attach a hose to the end of the drain pipe and time how long it takes to fill a container. Also, the investigator must be certain to clear away any electrical cords or devices that might pose a danger. Repeat this measurement as necessary using the guidelines for reading equipment flow meters.

For larger equipment, an ultra-sonic flow meter is the best measurement choice. These meters measure reflected sound waves in a pipe and read flow velocities (feet/second) using the Doppler Effect. These devices can display volumetric flow rates (gallons/minute) when pipe size is given as an input value and have an integrating function which displays total flow (gallons) after a given start time. When used in conjunction with a data logger the flow meter can produce results that show graphically how flow cycles over periods of days or weeks. This makes it much easier to determine an average flow for a device such as a cooling tower that has high flow and has high variability in that flow.

Nevertheless, these devices have several drawbacks. They can only measure flow on full pipes and many drains and sewage pipes are only partially filled. The pipes must be above a minimum diameter, usually one inch. Worst of all the flow must have a reasonably well behaved velocity profile. If the profile is too turbulent or changes too rapidly the device will simply refuse to give a continuous reading. Instead it will alternate between periods of good readings and not reading (fault detection light is on). The manuals for these devices describe methods to try to get around these problems. The best readings are taken from straight pipe runs with five or more diameters of length between bends. Unfortunately, such runs are not always available and may still occasionally provide poor reading. If this happens the investigator will have to make a guess at what the average of the "good" readings might be. The only other alternative may be to shut down the machine and install a flow meter; an expensive and time consuming procedure.

3) Typical Building Systems and Measurements

3a) City Water Inlet

To do a mass balance on a building the city water flow into the building must be measured. If the drawings show the inflows are metered then these meters should be read over a period of several weeks. This will help to average out the daily fluctuations in the flow.

If the flow is not metered use an ultra-sonic flow meter and a data logger to measure it. This method provides data on both total inflow and on how water use cycles through its daily minimums and maximums. However, the cycling data are not strictly necessary for the study, only averages are. If there are several flows into the building it probably will not be possible to measure them all at the same time. Since we are taking averages over time and then adding them the fact that the measurements are for different time periods should not cause an excessive amount of error. If after taking these measurements there is reason to suspect that a typical time period was not taken then additional data should be gathered.

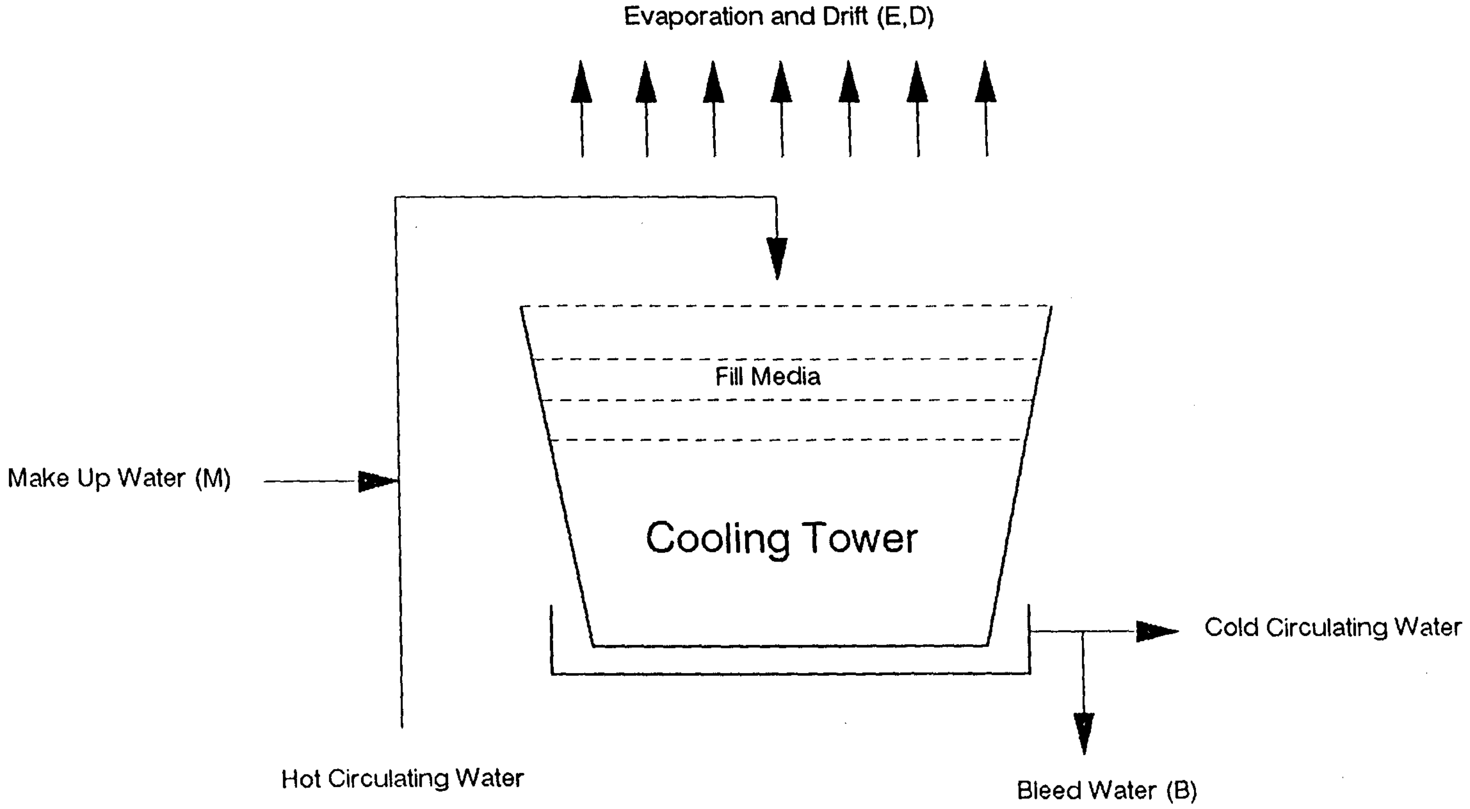
3b) Cooling Tower

Cooling towers are one of a buildings most important systems and heaviest water users. Before making any measurements the investigator must be completely familiar with their principals of operation and how they are affected by fouling. The cooling tower's purpose is to remove heat from the building that has been absorbed by the air conditioning system or to directly cool certain pieces of equipment. This is done (see Fig.6) by circulating water that has been cooled by the tower through the heat exchanger of the equipment that needs to be cooled or through the refrigeration unit for the air conditioning. Cooling down the equipment heats up the water. This water is then pumped back to the cooling tower where it is cooled and the cycle begins again.

Cooling towers work on the principal that if a portion of a body of water evaporates the remaining body of water will be cooled by the amount of heat that the water that evaporated used to change from liquid to vapor. This is analogous to cooling through perspiration on the human body.

Figure 6 shows a typical tower arrangement. Warm water

Fig. 6 Cooling Tower Flow Diagram



is sprayed down into the tower by fine mist jets. These droplets drizzle down through some type of fill media such as wooden slats or corrugated plastic strips while a fan (not shown) blows air through the tower in an upward direction. This air flow causes some of the water to evaporate and removes a small amount of water in the form of liquid aerosol particle. These aerosol particles, known as "drift", appear as mist above the tower. The fill media in the tower slows and spreads out the water flow so that it has a large surface area in contact with the air for an increased period of time. This increases the amount of evaporation and so the amount of heat removed from the circulating water.

Since the water that evaporates is pure and the starting water is city water with dissolved and suspended contaminants, impurities gradually become concentrated in the circulating water. This accumulation can degrade the tower's function by causing scale, corrosion or biofouling to form on the tower's components.

Scale is formed when the concentration of a dissolved mineral in the circulating water becomes so high that it can no longer remain in solution. A portion of the mineral comes out of the solution to form a hard rock like layer of calcium carbonate and other substances on the cooling tower components and piping. This reduces the surface area of the fill media and the flow capacity of the piping. This in turn reduces the cooling capacity of the tower.

The second of these fouling processes is corrosion. Corrosion in a tower takes place when two parts of a metallic component or two separate components exchange electric charge becoming in effect a weak battery when wet. The positive terminal or "anode" of this battery erodes away leaving deep pits or oxidized materials (rust) behind where originally there was solid metal. Low pH and high oxygen content in the water accelerate corrosion. The drip action of the tower tends to increase the dissolved oxygen in water and wash out smog components like oxides of nitrogen and sulfur. These oxides then form highly corrosive nitric and sulfuric acids which lower the pH of the water (3). The evaporation of pure water from the tower concentrates these acids even further. Taken together the above accelerates corrosion problems in UCLA towers. As this progresses the metallic components of the tower gradually disintegrate causing the need for repairs and the degradation of tower function.

A third fouling process is biofouling. Biofouling is the growth of microorganisms like algae, slime molds, fungi and bacteria in cooling towers to the extent that they degrade cooling tower function. This degradation is similar to that caused by scaling in that it physically clogs the system. It is different in that it also attacks wooden components of a tower causing them to slowly decompose. Microbes need a food source to survive. They get this food by either eating the wooden parts of the tower or from food in the circulating water. This food comes from dust particles that are scrubbed out of the air and from particles and dissolved substances present in the city water make up (3). This food supply is concentrated by the evaporation from the tower making the tower an excellent environment for microbial growth.

Besides the problem of cooling tower efficiency there is another microbial problem closely associated with biofouling that must be a concern: the bacteria Legionella. Legionella causes serious respiratory infections and is known to colonize cooling towers, especially those with large amounts of algal growth. This is because the algae produce substances which the Legionella use as nutrients. This bacteria can be spread by the drift particles from cooling towers. As a consequence, keeping a tower free from excessive microbial growth is a health concern not just an economic one.

There are two primary ways of preventing fouling. These are; bleeding the tower and adding protective chemicals. Tower chemistry is described in Appendix 8b.

The first line of defense against all of the above types of fouling is to reduce the concentration of tower foulants by injecting fresh water, known as make up water, and by removing some of the water with the concentrated impurities, known as bleed water (or "blow down") (see Fig. 6). It is this make up and bleed water that the investigator needs to measure.

Bleed water cycles are usually controlled by conductivity meters which measure the electrical resistance of the circulating water. This resistance is a measure of the concentration of dissolved solids in the water. Since the whole tower also cycles on and off depending on building demand the resulting bleed and make up cycles can be quite complicated. However, for this report the investigator only needs to measure the average amounts. A minimum of two weeks data for the make up water and a week's worth of bleed water data are recommended for a large cooling tower to ensure that a reasonable amount of averaging has taken place.

The above times were chosen to provide a balance between the cost of gathering cooling tower data and any additional accuracy that might be gained by using longer times. The flow measured depends on the amount of time that the tower runs each day which largely depends on the weather. Even if measurements were taken for a full year to average out seasonal fluctuations there would still not be enough data for perfectly accurate results. The following table that shows the sum of the number of days times the number of degrees above (cooling) or below (heating) the average temperature shows this:

Degree Days

Type	1991	1992	30-Year Average
Heating	1,277	769	1,819
Cooling	564	518	615

Yearly variations in temperature are very high which in turn causes a high variance in cooling tower usage. This puts a limit on the accuracy of even a year long cooling tower analysis. Because of this, taking measurements for a couple of weeks gives a reasonable balance between accuracy and the cost of the investigators time.

If an analysis of the cooling tower itself, instead of the whole building, is to be a primary objective then another approach can be taken. Conductivity measurements of the make up and bleed water can provide the necessary data for an analysis (see section 6a). One or two measurements of make up conductivity should be sufficient. More than one measurement is needed because city water conductivity can vary for seasonal reasons and because of changes in the blending of the various well and reservoir waters that are its constituents. A number of measurements for the bleed will also be necessary. This is because the concentration of the circulating water in the tower fluctuates depending on when the tower was last bled. If large fluctuations are encountered then more measurements must be taken so that an average can be established.

Two things the investigator must look for on cooling towers are extra make up water and bottom spray. Left over water from some other process such as concentrate left over from a reverse osmosis plant is often pumped into the top of cooling towers as extra make up water. This way the water is reused instead being wasted. This water must be measured and added to the make up water total for the analysis to be correct.

Bottom spray is often used on old towers that can no longer handle the building heat load. Fine mist sprayers are mounted underneath the tower and spray cold city water onto the bottom of the tower in an effort to cool down the reservoir of water located there. If the drip from this is caught in a pan and used in the tower, it should be measured and considered as make up water. If the spray rains down on the roof and goes to drain it should be measured and included as part of the gallons per day the tower uses but not included in the concentration calculations of the analysis.

3c) Purified Water Systems

Reverse osmosis is a process where a membrane separates pure water "product" from water that has dissolved and particulate impurities. This pure product is used in place of distilled water for many experimental and medical purposes throughout the campus since it is cheaper to produce. When a lab or medical spigot in a building reads "distilled water" it is often actually reverse osmosis purified water. Less pure forms of purified water are also made on campus but these typically just have one or more of the following steps removed.

To begin the process the water supply is filtered of as much particulate matter as possible to avoid clogging the membrane. Usually the water is then dosed with chemicals or run through a water softener to prevent scale from forming on the membrane. Then, to remove chlorinated organics, the water passes through a carbon filter. The water is then run parallel to the reverse osmosis membrane at high velocity and pressure inside a rigid casing. A small flow of very pure water passes through the membrane and is stored on site for latter use. The rest of the flow with elevated levels of impurities called "concentrate", is left over as waste. It is this concentrate that is often used as extra make up in cooling towers. It is also important to note that a system for making less pure water such as one with no reverse osmosis membrane would have a much higher ratio of product flow to concentrate than the above system.

Reverse Osmosis plants typically have flow totalling and flow rate meters. Usually these plants are maintained by an outside maintenance service company that keeps a log of performance. A typical schedule is one to two visits per week. The investigator should phone the company and arrange to talk to the service representative during the next visit. These logs contain flow data for periods of months and so give all the needed data for finding the average product water produced. The concentrate water flow usually has a flow rate meter but no flow totalling meter and so needs to be measured and averaged.

Flow accounting in a reverse osmosis plant depends on where the concentrate goes. If the concentrate goes down the drain then both it and the product water should be counted as the water usage for the plant. If the concentrate is diverted from the drain to be used somewhere else (such as a cooling tower) then it should be counted as a part of that other process.

A side issue in reverse osmosis plants is regeneration of water softeners (ion exchangers). Water softeners lose their effectiveness as they near their maximum capacity to adsorb minerals. To regenerate this capacity they are typically back flushed with a dilute acid solution made from city water and concentrated acid. It was found that despite the high flow rates used (20 GPM in MBI) the amount of time that was required (30 minutes/week in MBI) was small enough that this water use could often be neglected. However, this may not be applicable in all buildings. This evaluation will have to be done on a case by case basis. The effluent from this regeneration process has a very high calcium content and must be disposed of as sewage. Attempts to reuse this water in a cooling tower or other apparatus would tend to cause scaling problems (see section 3b).

3d) Instrument Coolers

Some laboratory instruments need water for cooling. The usual method is to install a prepackaged instrument cooler with a closed circulating loop of water on the equipment (hot) side and city water that dumps to drain on the cold side. For example, electron microscopes usually run continuously and have an instrument cooler to provide for their cooling needs. Water is always flowing on the instrument circuit in the cooler but typically shifts between on and off or high and low flows on the city water side. Depending on the manufacturer, the instrument cooler may have several operational modes each with its own constant flow rate. This requires the investigator to measure each of the flow rates and the duration of each flow rate. This information is used to calculate the weighted average flow rate for the instrument (see section 4b). Measurements of instrument cooler flow rates are usually made with the graduated container method.

4) Data Reduction for Input

4a) Database

The purpose of the database (App. 8c) is to organize the data that accumulates from the building surveys. The database converts the survey sheet information into yearly cost estimates. These cost estimates can be used in the analysis phase of the study to help locate areas of interest for water conservation.

4b) Flow Rates

Equipment with only one constant flow rate is the simplest to put into the database. In the column Max GPD input the device flow rate in Gallons/Day. In the column Factor of Use put down the fraction of a full day that the device is typically used. For equipment that is not used on the weekends multiply the weekday usage by five sevenths to get the daily average. The Factor of Use information comes either from a device's log book, reports from the user, or a guesstimate by the investigator based on similar equipment.

For equipment that has distinct flow modes, such as an instrument cooler, a time weighted average flow is used. For example, the instrument cooler on a Hittachi H-7000 electron microscope has two measured flow modes; 2.64 GPM for 2 minutes and 1.13 GPM for 6 minutes. These flow modes were observed to cycle without apparent variance and were observed on two occasions. The weighted average of these two modes is approximately 1.5 GPM:

Weighted average=

$$\frac{(2.64GPM)\times(2Min)+(1.13GPM)\times(6Min)}{(2Min)+(6Min)}=1.5GPM$$

The Factor of Use in this case it is one, electron microscopes are rarely turned off.

If instead a totaling flow meter is used to measure the flow over a period of time, such as with a cooling tower, the reading divided by the time elapsed between readings of the meter is the average flow. As an example, the readings at the MBI cooling tower meter were 5,538,880 Cubic Feet on 7/20/93 and 5,895,180 Cubic feet on 8/16/93. There was also an additional 6 GPM of make up water coming from the waste concentrate of a reverse osmosis plant and 13.4 GPM additional make up from an auxiliary make up water line. The cooling tower water usage for input into the data base is then:

Gallons per day from metered source=

$$(5{,}895{,}180Ft^3)-(5{,}538{,}880Ft^3)\times\frac{7.481Gal/Ft^3}{27Day}=98{,}721GPD$$

Gallons per day from other sources=

$$((6GPM)+(13.4GPM))\times(60Min/Hr)\times(24Hr/Day)=27{,}936GPD$$

Total gallons per day=

$$(98{,}721GPD)+(27{,}936GPD)=126{,}657GPD$$

Note: When an average Max GPD was established using a flow totaling meter over a period of days that the Factor of Use must be set to "1". This is because there is no way for the investigator to determine how often the equipment was actually in use. The idea is that the column Max GPD times the column Factor of use must equal the average daily water use for that piece of equipment. The prices for water purchase and sewage disposal used in the database are from the Annual Energy and Water Conservation Report put out by UCLA Facilities Management (9).

4c) Zero Flow Equipment

Zero flow equipment is equipment that is hooked up but not in use. However, equipment that is not operating today might be in use at some at some future survey date. So, to facilitate the site inspection phase of future surveys this equipment must be listed.

4d) Data Check

Once the collected water use data has been put into the database it is important to check the measured total against the total water supply measured from the inlet. The sum of the measured water use should turn out to be less than the inlet because water for sanitary purposes was not measured. If the measurements are within about 25% of each other then it is reasonable to assume that the analysis is correct. If they are not within 25% of each other then a problem exists. Either some of the measurements were made incorrectly or something important was missed. For example, an extra city water inlet or a major water user might have been overlooked.

At the Molecular biology Institute, MBI, the main city water flow was measured at an average of 78.3 GPM. An additional 31 GPM average was coming in from an adjacent building for a total of 109.3 GPM average supply. The total average usage estimated was 106.7 GPM (from 153,684 GPD average flow in App. 8c). The difference between the two measurements is 2.6 GPM. The question is whether or not this difference is significant.

To determine this the average number of building residents and any special water uses that might occur must be examined. In the case of MBI the Facilities database shows 84 work stations (designated locations where people work) for the building. This works out to 14 people for each of its six occupied floors.

The on-site investigation showed anecdotally that this is a reasonable number. The reason that some sort of verification is necessary since the number of work stations is not always a good indicator of the number of building residents. Classroom seats are on the database and should normally be counted the same as residents.

MBI does not have any special sanitary water needs like a food facility. But, it does have a laboratory type dishwasher on each floor which is used every other day on average. Taken together, the above indicates that the total inlet water should exceed the measured use but, not by a large amount. The difference of 2.6 GPM comes out to 3,744 GPD or about 44.6 gallons per person per day for unmeasured uses. This amount seems a bit small given the type of research that is going on. It probably means that the factor of use for some of the equipment was over estimated and that the close match between the in and out flows was fortuitous.

Besides installing water conserving valves there is little that can be done about sanitary water use. These valves are already installed at most campus locations. However, if the investigator is looking at a building with significant class space (MBI has no classrooms) it might be worth while to add the following calculation to the measured water use amount before comparing it with the inlet water.

Estimated lavatory use=
(3 Flushes/Person Day)x(5 Days Used/7 Days Total)
x(Number of Work Stations + Class space))x(3.6
Gal/Flush)

A sample calculation for Haines Hall (a building that mostly houses classrooms):

Estimated Lavatory use=

(3 Fl/P/Day)x(5/7)x(605 Spaces)x(3.6 Gal/Fl)=4,667 GPD

or 3.2 GPM

5) Identifying Feasible Conservation Project Candidates

The next step is to select the pieces of equipment on the database most likely to provide opportunities for significant conservation for further analysis. Several criteria for this selection are possible. The most obvious is high water use. Cooling towers are generally the most intensive water users in a building and so fall in this category. A second criteria is ease of improvement. Repairing leaking pipes would fall into this category. Equipment that has a specified flow rate on the building drawings that seems to be exceeded in practice should also be looked at. A more difficult assessment is for connecting several pieces of equipment that are spatially and technically related.

5a) Selection Criteria For Equipment Rooms

First, the total water usage of these pieces of equipment must be large enough to justify a significant expenditure. Second, the equipment must be related so that the resultant system makes some functional sense. Putting two pieces of equipment on the same cooling circuit means that both will go down if the circuit goes down. This may not be a problem if one piece of equipment has a functional need for the other to operate or if some kind of redundancy can be established in the cooling system such as the ability to use city water for once through cooling. Last, is that the cycles of operation of the pieces of equipment must match or it must be practical to instal controls that can compensate for variances in demand due to mismatches in demand cycles.

Equipment that runs continuously needs little in the way of controls. An excellent example of this (see App. 8c) is the group of X-ray cooling machines and the walk in refrigerator in MBI room 116. The total water usage is 10,750 GPD, a significant amount. The refrigerator chills samples for the X-ray machines and so is functionally connected to them. All the machines run continuously and are located in one room. This example is analyzed in detail section 8b.

6) Cost Analysis and Improvements

6a) Cooling Towers

The objective in cooling tower analysis is to see if water can be conserved by reducing the need for make up water by reducing bleed. The limitation on the reduction of bleed water is that as previously mentioned, bleed prevents the accumulation of the dissolved substances present in the make up water. This accumulation of dissolved material is measured by the "concentration ratio" of the tower, defined below.

Deriving the formulas necessary for cooling tower analysis is done in a relatively straight forward manner using conservation of mass and a few approximations. The following abbreviations will be used:

B	Bleed Water (GPM)
CB	Concentration of substance(s) in the Bleed Water (Mass/Volume)
CM	Concentration of substance(s) in the Make Up Water (Mass/Volume)
CR	Concentration Ratio (Dimensionless)
E	Evaporation (GPM)

D	Drift (GPM)
DR	Drift Rate (% of maximum circulating flow)
C	Maximum Circulating Flow (GPM)
M	Make Up Water (GPM)
F	Actual Factor of Use (Dimensionless)

Note: The calculations are equally valid using GPM or any other consistent set of units such as total volume measured for a given period. All sample calculations are done in terms of average values.

For this system (Fig. 6) conservation of the mass of water entering and leaving the tower can be expressed as:

(1)

$$M=E+B=D$$

Make up and bleed water are measured quantities. Drift is approximated in the following way:

(3)

$$D=\frac{DR}{100}\times C\times F$$

Maximum circulating flow for a tower can be obtained from the specifications in the building's HVAC drawings. Actual factor of use is assumed to be 0.4 unless the actual use is known (Note: This is different than in the data base where for measurement purposes it was usually set to "1"). Drift rates are always small, ranging from about 0.002% to 0.2%. Since these rates are small, actual drift losses are very small. Drift rates depend on the tower type and manufacturer. Appendix 8c has a listing of the most common types at UCLA. The only other source of these rates is the manufacturer. Once the drift has been calculated the concentration ratio can be calculated from the above CR equation.

Another approach to finding the CR is to use the mass balance of the dissolved material entering and leaving the tower:

(4)

$$CM \times M = (CB \times B) + (CB \times D)$$

By rearranging and combining with the formula for CR the result is:

(5)

$$\frac{CB}{CM} = \frac{M}{B+D} = CR$$

This equation is useful because it yields a different method for finding CR; measuring the concentrations of dissolved materials. The total amount of dissolved solids in a water sample is roughly proportional to the conductivity (micro-mhos/cm) of the sample. So, by measuring the average conductivity of the bleed and make up water CR can be found without measuring flows.

Another useful formula can be derived by combining the formulas for conservation of mass and CR, neglecting drift. An approximate value for B in terms of E and CR is:

(6)

$$B = \frac{E}{CR-1}$$

Note: This formula becomes undefined when CR approaches 1. Also, for very low CRs drift cannot be neglected.

If drift is not neglected then the above formula would be:

(7)

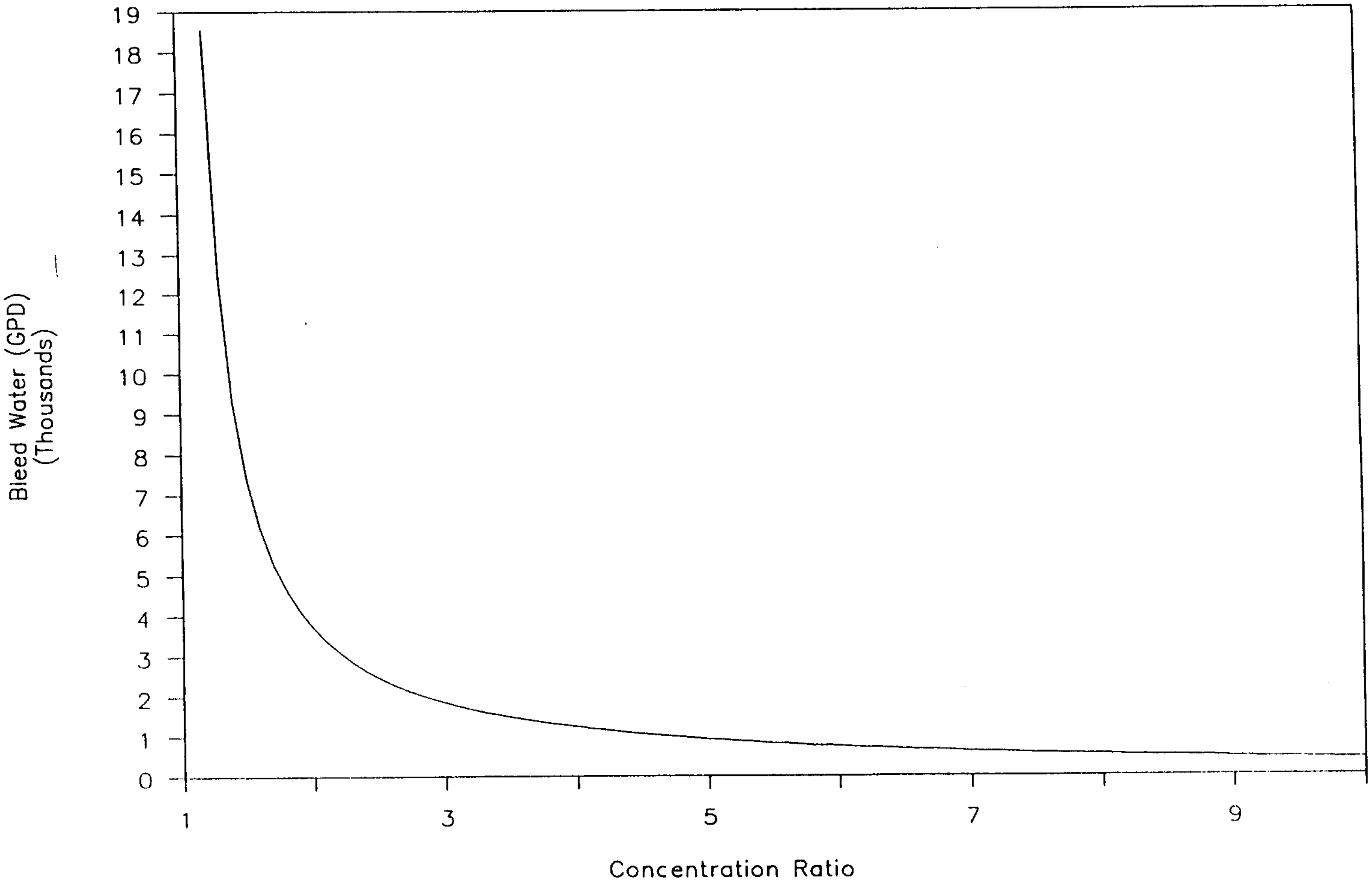
$$B=\frac{(E-D(CR-1))}{CR-1}$$

The evaporation in the above formulas is a constant for any given amount of cooling (Note: Cooling capacities of cooling towers are usually given in Tons where 1 Ton=12,000 BTU/Hr). Once the amount of evaporation is found CR can be varied to find the amount of bleed water saved:

Latent Heat of Vaporization for water at 1 Atm.=970.3 BTU/Lb

Fig. 7 Expected Bleed Water

(100 Ton Cooling Tower)



Density of 212 F. Water=59.8 Lb/CF

Evaporation (Gallons/Ton/Day))=

(8)

$$\left(\frac{1}{970.3\,BTU/LB}\right)\times 12{,}000\,\frac{BTU}{Ton\text{-}Hr}\times\left(\frac{1}{59.8\,LB/Ft^{3}}\right)\times\frac{7.481\,Gal}{Ft^{3}}\times\frac{24}{D}$$

37.1 Gal\Ton\Day

However, in addition to evaporation a small amount of cooling takes place due to convection between the air and the water when the ambient air temperature is colder than the circulating water temperature. Of course, on a very hot day this could potentially be reversed. Since air temperature varies widely and this effect is small it is normally assumed to reduce the amount of cooling water needed by 5% (1,3):

(9)

$$\left(37.1\,\frac{Gal}{Ton\text{-}Day}\right)\times(1-0.05)=35.2\,\frac{Gal}{Ton\text{-}Day}$$

This is the amount of water needed if the tower ran continuously. However, most towers turn on and off during the day and often do not run at night at all.

For doing a comparison a factor of use of .4 is appropriate:

(10)

$$(35.2\frac{Gal}{Ton\text{-}Day})\times(.4)=14.1\frac{Gal}{Ton\text{-}Day}$$

Note: This 14.1 Gal/Ton/Day is only an approximate figure. It should not be used when there is measured flow or conductivity data available.

An example of an appropriate use would be to approximate the bleed of a tower under two different conditions:

For a 100 Ton cooling tower with a CR of 2 the expected Bleed would be (neglecting drift):

$$B=\frac{(14.1\frac{Gal}{Ton\text{-}Day})\times(100Ton)}{2-1}=1,410Gal/Day$$

If the CR were raised to 3 the Bleed would be:

$$B=\frac{(14.1\frac{Gal}{Ton\text{-}Day})\times(100Ton)}{3-1}=705Gal/Day$$

These formulas show that to conserve bleed water CR must be increased as much as possible. The kind of improvements that are available over a range of CRs are shown graphically in Fig 7. At low CRs raising the CR will lead to a big improvement in the amount of bleed water used. When starting from high CRs increasing the CR has only a marginal decrease in bleed. Therefore, a low CR tower is the ideal candidate for improvement.

The limitation on how high to raise the CR is fouling. How high the tower can go without excessive fouling depends on the method used to treat the water. Here are some suggested levels (3):

Concentration Ratios of Up To:	Method
1.5	Bleed with no chemical treatment
3.5	Conventional chemical treatment carefully operated and or filtration to assist treatment
6	Acid Treatment and conventional

	chemistry
10	Ozonation

At UCLA most towers use bleed and chemical treatment. Taking into account the age of most of the campus towers and the fact that UCLA has "hard" water an efficient tower could probably be expected to run at a CR of 3 (Note: This CR is consistent with many of those that were actually surveyed). Chemical treatment of water is described in Appendix 8b.

The investigator's primary responsibility is to identify towers that need better treatment and give an approximate dollar value to the savings that might be achieved. For instance, in the previous example of the 100 Ton tower moving from a CR of 2 to 3 the expected yearly savings would be:

Cost of purchase and disposal of a of water=.00325 \$/Gal

Factor of use=.4

Savings=

$$(1{,}410GPD-705GPD)\times(365Day/Yr)\times(.00325\$/Gal)=836\$/Yr$$

It seems likely that the cost of the extra chemicals and tower cleaning to raise the CR without excessive fouling would probably be less than 836 $/Year. The investigator would need to contact the local representative of UCLA's chemical supplier to get a better estimate.

Tower Example

The two towers on MBI are examples where improvement is possible. They will soon be replaced by a connection with the new Co-generation facility and are not actually candidates for repair. However, they do provide a good illustration of the analysis technique.

These towers are connected by an equalizing line and effectively function as one tower. The problem is that on one side the float which is supposed to regulate make up is broken. The conductivity meters which are suppose to trigger bleed may not be working properly either. This has led to a situation where there is too much make up being used, causing a low CR. The details are:

Make Up Water	88 GPM
Bleed Water	70 GPM
Drift Rate	0.2%
Maximum Circulating Flow	2,658 GPM

Factor of Use 0.4

To find the CR the Drift must be determined:

$$D=\frac{DR}{100}\times C\times F=(\frac{.2}{100})\times(2,658GPM)\times(.4)=2.1GPM$$

$$CR=\frac{M}{B+D}=\frac{88}{70+2.1}=1.2$$

If the tower could be improved to a CR of 1.5 the approximate evaporation, bleed and cost savings would be:

$$E=M-(B+D)=88GPM-(70GPM+2.1GPM)=15.9GPM$$

$$B=\frac{E+D(1-CR)}{CR-1}=\frac{15.9GPM+2.1GPM(1-1.5)}{1.5-1}=29.7GPM$$

Water saved=

$$(70GPM)-(29.7GPM)=40.3GPM=58,032GPD$$

Cost savings per day=

$$(.00325\$/Gal)\times(58{,}032GPD)=189\$/Day$$

Were this tower not about to be shut down repairs to its control system would probably be justified. Also, the actual savings would not be the 189 $/Day calculated since the cost of chemical treatment additives must be factored in.

6b) Chemical Additive Costs

The analysis necessary to determine the amount of additive needed for different conditions in the tower is beyond the scope of this report. However, once the amount required has been determined through calculations or estimated through experience the cost for the current and proposed systems can be estimated from the following (units are those commonly used by chemical manufacturers):

A	Cost of Additive(s) ($/Lb)
Bc	Current Bleed (Gal/Day)
Bp	Proposed Bleed (Gal/Day)
Cc	Current Additive Concentration (Fluid Ounce/1000 Gal)
Cp	Proposed Additive Concentration

	(Fluid Ounce/1000 Gal)
Da	Density of Additive (Lb/Gal)

Current Additve cost=

$$Da\frac{Lb}{Gal}\times\frac{Gal}{128Fl.Oz.}\times A\frac{\$}{Lb}\times Cc\frac{Fl.Oz.}{1000Gal}\times Bc\frac{Gal}{Day}$$

The proposed additive cost can be calculated in a similar fashion but with Bp used instead of Bc. These calculations should be repeated for each additve in the system. The total cost increase (savings) for the proposed system =

Sum of proposed costs - Sum of Present costs

For the example of improving the MBI cooling towers to a CR of 1.5 the cost of chlorine based additive (Nalco 2593) would be:

A	1.52 $/Lb
Bc	100,800 Gal/Day
Bp	42,768 Gal/Day
Cc	1 Fl. Oz./1000 Gal
Cp	1.3 Fl. Oz./1000 Gal
Da	8.3 Lb/Gal

Present cost=

$$8.3\frac{Lb}{Gal}\times\frac{1Gal}{128Oz.}\times1.52\frac{\$}{Lb}\times\frac{1Oz.}{1000Gal}\times100,800\frac{Gal}{Day}=9.94\frac{\$}{Day}$$

Proposed cost=

$$8.3\frac{Lb}{Gal}\times\frac{1Gal}{128Oz.}\times1.52\frac{\$}{Lb}\times\frac{1.3Oz.}{1000Gal}\times42,768\frac{Gal}{Day}=5.48\frac{\$}{Day}$$

Cost increase (savings)=

$$5.48\frac{\$}{Day}-9.94\frac{\$}{Day}=-4.46\frac{\$}{Day}$$

This small savings represents only one chemical additive but similar results could be expected for the others. This means that for towers with a very low CR the controling cost component is water cost. Chemical costs can be considered negligible. However, for a higher CR tower the situation could be reversed.

6c) Equipment Rooms

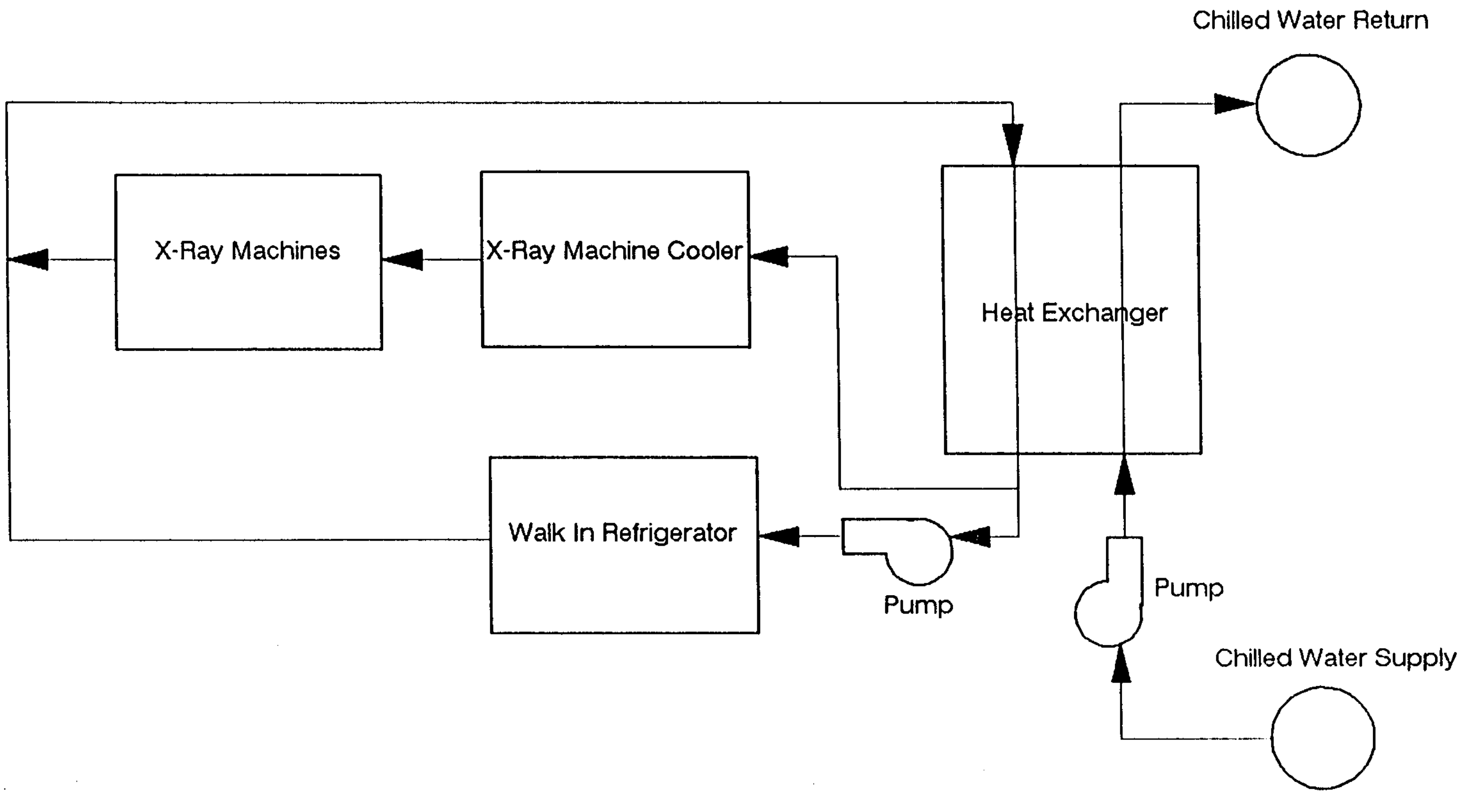
Sometimes an area in a building needs to be examined because several pieces of equipment, grouped together, have high water use. The criteria for selecting such an area was previously discussed. The analysis will be different for each case but broadly the steps are: find the value of the water being used, propose an alternative (or alternatives), determine the approximate cost of the alternative, and compare the costs and expected savings of the design using the pay back period method.

Equipment Room Example

Room 116 in MBI has a number of water-using pieces of equipment that could all be cooled by the same system. The present set up is to have city water cooling a series of equipment coolers and a walk in refrigerator. After being used for cooling this water dumps to drain. The alternative would be to pipe in chilled water from the building's supply (soon to be from the Co-generation plant) and run that water through a heat exchanger. A heat exchanger is used because piping chilled water directly through the equipment risks adverse chemical reactions between the chemical additives in the chilled water and the equipment.

In this design the hot side of the heat exchanger would be connected to the x-ray machine coolers and the walk in refrigerator (Fig 8.). The equipment coolers have

Fig. 8 Proposed Equipment Room Flow Diagram



their own built in pumps and controls which would be retained. A pump would have to be installed on the hot side of the heat exchanger to make up for the loss of working pressure from the city water line that was previously connected to the refrigerator. The cold side of the heat exchanger would be connected to the chilled water supply and return pipes and would also need a pump to ensure adequate flow. The system details are:

Present cooling water flow	10,750 GPD (7.5 GPM)
Chilled water temperature	45 F
City water temperature	65 F
Equipment cooler water outlet temperature	80 F
Pressure drop through heat exchanger and cold side piping (assumed)	20 PSI
Pump delivery and motor efficiencies (assumed)	80% (0.8)
UCLA electrical cost	0.07 $/Kw-hr
Chilled water cost from the Co-generation plant	0.16 $/Ton-Hr

A 100% factor of safety on the cooling load will be applied in this design. As an aside, the ability to use city water cooling for emergencies or during maintenance should be retained. This would be achieved by valving off the present piping while leaving the connections in place.

Before calculating the cost of the proposed system the current cost should be determined. If this cost is low then there may not be a need to propose a new system. The current cost is for water only:

Cost=

$$10{,}750 GPD \times 365 \frac{Day}{Yr} \times 0.00325 \frac{\$}{Gal} = 12{,}752 \frac{\$}{Yr}$$

Since this cost is significant, an analysis is warranted. To establish the cost for the proposed system the electrical cost associated with the pumps must be found. To do this the cooling capacity and flow rate of the system must be known.

The present cooling capacity is:

(11)

$$Q=M\times Cp\times DT$$

Where:

Q Cooling Capacity BTU/Hr

M Mass Flow Rate Lb/hr

DT Temperature Rise (between the city water inlet

and the equipment cooler outlet)

Cp Specific Heat of water; 1 BTU/Lb/F

Substituting the above data:

$$Q=(448GPH)\times(\frac{1}{7.481Ft^{3}/Gal})\times(62.2Lb/Ft^{3})\times(1\frac{BTU}{Lb-F})\times(80F-6$$

55,873 BTU/Hr or 4.7 Tons of refrigeration

A 100% factor of safety means that the design will use pumps and heat exchangers sized for a larger load. But, to make a correct comparison between proposed and actual systems, the load for the rest of the economic analysis still needs to use the estimated actual load. The heat exchangers maximum design load is:

$$(4.7\,Ton)\times(2)=9.4\,Ton=112,800\,BTU/Hr$$

With chilled water instead of city water the expected efficiency of heat exchange will be greater because the chilled water is much lower in temperature than the city water. For the calculation assume that this will yield a 20 degree rise in cooling water temperature instead of the current 15 degree rise (These estimates are averages from manufacturer's data for several models of plate and frame heat exchanger). So, the chilled water temperature in the new design rises from 45 F to 65 F. With this assumption the maximum flow rate of the chilled water can then be calculated:

Q=112,800 BTU/Hr=

$$(X)\,GPH\times\left(\frac{1}{7.481\,Ft^3/Gal}\right)\times 62.2\,Lb/Ft^3\times 1\,\frac{BTU}{LB\text{-}F}\times(65F-45F)$$

solving for X: X=678 GPH or 11.3 GPM.

With the maximum flow rate known the pump can be sized by finding the brake horse power and then electrical input horse power required (6):

(12)

$$Bhp=\frac{F\times DP\times Sp}{3960\times Pe}$$

Where:

Hpb	Brake Horse Power
F	Flow Rate (GPM)
DP	Pressure Drop (Feet of water)
Sp	Specific Gravity of water; 1 (Dimensionless)
Pe	Pump Efficiency

In this case:

$$Hpb=\frac{(11.3GPM)\times(20Lb/sq.inch)\times(2.31\frac{Ft}{sq.inch})\times(1)}{(3960)\times(.8)}=0.16Hp$$

To find wire horse power from brake horse power divide by the motor efficiency:

$$Ehp=\frac{Bhp}{Me}$$

Where:

Hpw	Wire Horse Power
Me	Motor Efficiency

For this example:

$$Hpw=\frac{0.16}{0.8}=0.20Hpw$$

The nearest fractional horse power motor is 1/4 Hpw. For this cost estimate assume that the pump for the refrigerator will be the same size. Actually, flow on the equipment (hot) side would need to be slightly larger than that on the cold side because of the smaller temperature difference on that side.

The annual electrical consumption of the proposed system is then:

$$(2)\times(\frac{1}{4}Hpw)\times(0.7453Kw/Hp)\times(8760Hr/Yr)=3,264Kw\text{-}Hr/Yr$$

Yearly electrical cost of proposed system:

$$(3,264Kw\text{-}Hr/Yr)\times(0.07\$/Kw\text{-}Hr)=229\$/Yr$$

Cost of chilled water from the Co-generation plant:

$$(0.16\frac{\$}{Ton\text{-}Hr})\times(4.7Ton)\times(8760Hr/Yr)=6,588\$/Yr$$

Total cost per year for the proposed system:

Yearly cost=electrical cost+chilled water cost=

$$(229\$/Yr)+(6{,}588\$/Yr)=6{,}817\$/Yr$$

The annual savings would then be:

Savings=present costs-expected savings=

$$(12{,}752\$/Yr)-(6{,}817\$/Yr)=5{,}935\$/Yr$$

In addition to annual costs there is also a time construction cost. These costs can be estimated from calls to vendors or from previous projects. The estimated costs for this system including labor are:

Heat Exchanger	2000$
1/4 Hp pumps X 2	2500$
1" pipe, 200 Ft	1500$
Insulation	1000$
Fittings (assumed)	2000$
Self operating regulator	1500$
Control for city water	1500$
Hot tap connections to chilled water mains	2000$
Subtotal	14000$

Contingency 15%	2100$
Engineering 10%	1400$
Total	17,500$

A quick method for deciding if it makes sense to pursue a design based on these estimated costs and savings is to determine the present value (PV) of the savings. To do this the expected rate of return on investment the life of the project and the salvage value must be known. For this example these are assumed to be 4%, 7 years and 10% of initial investment.

PV of savings over seven years=35,622$

PV of 10% of 17,500$=1,330$

PV of net savings=35,622$-17,500$+1,330$=19,452$

The higher the PV of the net savings the more desirable the project. Assuming limited investment dollars and multiple projects, the project with the highest PV would be funded first, the next highest second, etc. It must be noted that some projects with a negative PV might still be justified because of non-financial reasons such as regulatory compliance.

7) Summary

UCLA's water costs are increasing. There are two components to this cost, unit cost and the amount of water actually used. Unit costs are rising quickly but are out of UCLA's control. However, past experience has shown that usage can be significantly reduced by applying conservation techniques. This makes conservation a priority for reducing UCLA's expenditure on water.

An important part of campus water use is water used in buildings. This report addresses how to examine use in buildings, measure use, and analyze areas for potential conservation. This analysis provides a financial basis for expenditures for water conservation. In the case of cooling towers, health concerns related to the spread of Legionella provide another reason for equipment and process upgrading.

The study of water use in laboratory and classroom buildings can be broken down into a series of steps. The first step is for the investigator to become familiar with site by examining drawings, interviewing the important people connected with the building and actually walking the building. The next step is to make measurements of the water use requirements of the equipment and water sources identified in the first step. This collected data must then be reduced to a format that can be put into the database. At this point a "reality" check on the data should be made by comparing the estimated building water use with the sources that were measured. Next, those areas that seem promising for conservation must be identified. These areas are then analyzed to find out how much savings potential exists and the approximate costs involved. Areas that have the best potential for cost savings would then be recommended for a detailed analysis.

8) Appendices

8a) Equipment List

A wide range of equipment may be needed for a study depending on the situations encountered at a particular building. The following are useful pieces of equipment:

Graduated plastic containers (in the one, five and ten gallon sizes)

Rubber hoses (three feet long and in diameters 1, 1.5 and 2 inches for connecting equipment drains and measuring containers)

Assorted Hose Clamps (for attaching hoses and drain pipes)

Flashlight

Pass Key Ring

Ultrasonic Flow Meter

Data Logger (for above meter)

Locks (for Flow Meter and Data Logger)

Large Sack or Carrying Bag

Clipboard (with paper, pencils, etc.)

Survey Sheets

Calculator

Watch (with stop watch function)

Safety Glasses

Identification Badge

Paper Towels

Portable Computer (with port for Data Logger)

Water Conductivity Meter

Thermometer

8b) Chemical Treatment

An important method of preventing fouling in water systems is to add chemicals that interfere with the chemical or biological processes involved. Most additives have a specific type of fouling that they counteract. This means that treating a system for all three types of fouling (scale, corrosion and biofouling) requires the simultaneous addition and control of several chemicals (1,3,4,6).

Chemicals are lost each time the system bleeds off water and through the natural decomposition of the additives. The control system, whether manual or automatic, must be capable of detecting these losses and injecting additional additives to bring the system concentration back up to the proper level. Keeping the concentration of additives from going above the minimum necessary to prevent fouling is also important because chemical treatment additives are very expensive (5).

A typical UCLA control system includes tests for the following; alkalinity, chlorine, phosphate, and conductivity. All of these tests are performed as periodic batch tests with the conductivity also being measured continuously on most towers.

Alkalinity is essentially the ability of the water to neutralize strong acid. It is important because water with a high alkalinity normally has a high concentration of calcium bicarbonate. This dissolved calcium bicarbonate easily decomposes into calcium carbonate, carbon dioxide, and water when it is heated or there is a rise in PH (common situations in cooling towers). Calcium carbonate has a very poor solubility in water and so readily precipitates out as scale on system components (1,3,8). Knowing the alkalinity gives a measure of the scale forming potential of the water.

Chlorine is tested because it is a component of many biocides. These biocides are used up during the disinfecting process, broken down by sunlight, and removed by reactions with water borne contaminants. Therefore, frequent testing is needed to insure that biocide levels remain high enough to keep biofouling in check.

The phosphate test is performed to determine the level of organophosphate additive in the system. This additive is primarily used for scale control but has some corrosion inhibiting properties as well.

Water conductivity is tested to measure the total concentration of dissolved solids in the water. Through a combination of experience and chemical company distributor recommendations this test is used to determine when the maximum allowable CR of the system has been reached so that bleed can be initiated.

Chemical treatment is largely a matter of selecting which additives will solve particular problems at an affordable cost. This topic is too large to be dealt with in generalized form an this report. There are thousands of proprietary and non-proprietary additives on the market with new ones coming out all the time. However, the author observed a number of chemicals commonly in use at UCLA and these will be discussed. This list is not intended to be a comprehensive campus listing since only a limited number of sites were surveyed.

For scale control the two common additives observed in use were acrylic polymers and organophosphates. Acrylic polymers have two scale inhibiting actions. First, they increase the negative surface charge of water borne particles causing them to repel each other rather than stick together. The second action is to prevent normal crystal growth in the scale deposit. Instead of large strongly adherent crystals small weak structures are formed. The organophosphates work by "sequestering" or reacting with ions in the water that would normally be deposited as scale. This reaction forms chemical complexes that tend to remain soluble instead of depositing as scale (1,5).

Corrosion control was frequently accomplished by the addition of sodium hydroxide and organophosphate additives. Sodium hydroxide is a base and is added to neutralize acids washed out of smoggy air by cooling towers. The addition of sodium hydroxide causes an increase in water PH which in turn causes a decrease in corrosion. This increase in PH also causes increased scale formation but, scale control additives were normally added to help mitigate this drawback. Organophosphates help prevent corrosion by combining with ions like calcium and iron in the water to form a tightly adherent film that protects the cathodic sites on metal surfaces from being a source for the charge needed for anodic corrosion (1,5).

The biocides used were primarily chlorine containing compounds such as sodium hypochlorite (5). Sodium hypochlorite in water decomposes to form hypochlorous acid and hypochlorite ion. Below PH 7.5 the main product will be hypochlorous acid. Above this PH there will be mostly hypochlorite ion. This is important because hypochlorous acid is about twenty times more effective as a biocide than hypochlorite ion (1). So, for optimum disinfection PH must be kept lower than 7.5.

This means that a careful balance must be drawn between the high PH needs of corrosion control and the low PH needs of scale and biofouling control. Raising the PH was accomplished as seen above by the addition of a base like sodium hydroxide. Lowering was done by adding an acid like sulfuric acid. Both these methods were observed in practice at various campus locations.

Appendix 8c

Water Usage Database

Last Update:9/9/93

Water $/Gal: 0.00153

Sewer $/Gal: 0.00172

Bldg:	Rm#:	Rm Code:	Instrument or Process:	Max GPD:	Factor of Use:	Yearly Cost:	Notes:
MBI	735a	Fac	R.O. water supply	1510	1.00	$1,791.24	To tower make up
MBI	735	Fac	Cooling towers (2)	126720	1.00	$150,321.60	Towers are connected
MBI	673	Lab	Beckman L5-75 centrif.	720	0.00	$0.00	
MBI	629	Lab	Beckman L5-75 centrif.	720	0.25	$213.53	
MBI	573	Lab	Beckman L5-65 centrif.	720	0.25	$213.53	
MBI	406	Lab	Beckman L5-65 centrif.	720	0.25	$213.53	
MBI	312	Lab	Beckman L8-70 centrif.	720	0.25	$213.53	Estimated
MBI	312	Lab	Beckman L8-70 centrif.	720	0.25	$213.53	Estimated
MBI	259	Lab	Beckman Du65 spect. photom.	144	0.50	$85.41	
MBI	259	Lab	Beckman L5-65 centrif.	720	0.10	$85.41	Rarely used
MBI	229f	Lab	Hitachi H-7000 elect. micro.	2170	1.00	$2,574.16	Continuous running
MBI	123	Lab	Beckman L5-65 centrif.	720	0.00	$0.00	Not in use
MBI	123	Lab	New Brunswick Fermenter	14400	0.25	$4,270.50	Not currently in use
MBI	106	Lab	ISI DS130 elect. micro.	1050	1.00	$1,245.56	Continuous running
MBI	A33	Fac	Vacuum pump	6840	1.00	$8,113.95	
MBI	A33	Fac	Vacuum pump	6840	0.00	$0.00	(Alternate)
MBI	116	Lab	Water Works RC16	1800	1.00	$2,135.25	X-ray machine cooler
MBI	116	Lab	Nes Lab HX500	2090	1.00	$2,479.26	X-ray machine cooler
MBI	116	Lab	Haskris R-500	2090	1.00	$2,479.26	X-ray machine cooler
MBI	116	Lab	Haskris R-500	1800	1.00	$2,135.25	X-ray machine cooler
MBI	116	Lab	Haskris R-150	500	1.00	$593.13	X-ray machine cooler
MBI	116	Lab	Walk In Refrigerator	2470	1.00	$2,930.04	
MBI	116	Lab	Haskris R-500	2090	0.00	$0.00	X-ray (alternate)
			Totals:	178274		$182,307.65	
			Sum of (GPD X Factor of Use):	153684			

Appendix 8d

Drift Rates

LOCATION	MFR	SERIAL NO.	MODEL	DRIFT RATE(%)	GPM	DRIFT RATE(GPM)
KNUDSEN	MARLEY	20-1-10-5-3	20-102	0.1	1472	1.472
FRANZ-EAST	MARLEY	8443-519925A	8443	0.002	390	0.0078
FRANZ-EAST	MARLEY	8443-519925B	8443	0.002	390	0.0078
FRANZ-EAST	MARLEY	8443-519925C	8443	0.002	390	0.0078
FRANZ-MIDD	BALT.	66096M	VNT80	0.2	240	0.48
FRANZ-MIDD	J.F. PRITCHARD	4319-04-0111	UN	NA	NA	0
POWELL	MARLEY	UN	369101	0.02	850	0.17
MATH SCIENCES (WEST)	BALT.	66-282M	TMA-500AL	0.2	1700	3.4
ENGINEERING 3	FLUOR	ACR-1955	4415	0.1	845	0.845
ENGINEERING 3	FLUOR	ACR-1954	4415	0.1	845	0.845
ENGINEERING 3	FLUOR	ACR-1953	4415	0.1	845	0.845
C.H.S.	MARLEY	656-12-254-6	UN	0.04	14340	5.736
NPI	MARLEY	A3011146	301	0.1	1236	1.236
MARION DAVIES	FLUOR	ACR-1921	10275-P	0.1	1200	1.2
MARION DAVIES	BALT.	78-817CM	CFT-2416	0.5	675	3.375
LIFE SCIENCES	BALT.	586071	175TM	0.2	250	0.5
LIFE SCIENCES	BALT.	UN	175TM	0.2	250	0.5
LIFE SCIENCES	BALT.	UN	150TMA	0.2	290	0.58
LIFE SCIENCES	BALT.	UN	150TMA	0.2	290	0.58

MBI	BALT.	73-3405M	VST-490B	0.2	1329	2.658
MBI	BALT.	73-3406M	VST-490B	0.2	1329	2.658
MURPHY HALL	BALT.	64-4182	TMA-400A	0.2	1100	2.2
MURPHY HALL	BALT.	73-2668M	V1-100-3	0.1	768	0.768
PAULEY	BALT.	81-2958M	CFT-2413C	0.5	600	3
PAULEY	MARLEY	6031471	603	0.02	2952	0.5904
SCHOENBERG HALL	BALT.	80-1452M	VXT-120C	0.002	450	0.009
YOUNG HALL	BALT.	66-111M	TMA-200A	0.2	582	1.164
YOUNG HALL	BALT.	61-9465	TMA-400S	0.2	825	1.65
YOUNG HALL	BALT.	61-9466	TMA-400S	0.2	825	1.65
GEOLOGY	BALT.	66-8492	TMA-400A	0.2	1100	2.2
GEOLOGY	BALT.	66-8491	TMA-400A	0.2	1100	2.2
GEOLOGY	MARLEY	UN	14-101	0.04	375	0.15

Appendix 8e

Water Allocation Survey Sheet

Date: 7/8/93
Page: 1

Investigator:	Bldg:	Contact Person(s) / Title(s) / Phone#(s):
William Aravanis	MBI	Donna Bryan, Lab Mgr. 58007 Dulio Cascio, Res. Assoc. 51551

Rm#:	Rm Code:	Instrument or Process:	Max GPD:	Factor of Use:	Notes:
735A	FAC	R. O. Water Supply	1510	1	Cooling Tower uses this waste
735	FAC	Cooling Tower (2)	126657	1	Towers are connected, flow measured by averaging over time, actual "F" unknown
673	LAB	Beckman L5-75 centrifuge	720	0	Room not in use
629	LAB	Beckman L5-75 centrif.	720	.25	
573	LAB	Beckman L5-65 centrif	720	.25	
406	LAB	Beckman L5-65 centrif	720	.25	
312	LAB	Beckman L8-70 centrif	720	.25	Estimated to be same usage as L5-65
312	LAB	Beckman L8-70 centrif	720	.25	" "
259	LAB	Beckman Du 65 spectro. photom.	144	.5	
259	LAB	Beckman L5-65 centrif.	720	.1	Log book shows use is rare
229F	LAB	Hitachi H-7000 elect. micro	2170	1	Cooling for this is never turned off
123	LAB	Beckman L5-65 centrif.	720	0	Moth balled, not plugged in

8f) Chronological List of Study Steps

The following is list of steps for studying a building. It will need to be adapted to the conditions present at each particular site. Some steps may require iteration:

1) Review Archival Data
2) Contact Building Personnel
3) Inspect Site
4) Verify Drawings
5) Measure Flows At Site
6) Reduce Data to Usable Format
7) Perform Mass Balance On Building
8) Identify Areas For Conservation
9) Analyze Conservation Costs

8g) References

1) Drew Chemical Co., Principals of Industrial Water Treatment, Boonton, NJ, 1978

2) Hambelton P., Dennis J., Fitzgeorge R., Survival of Airborne Legionella Pneumophila, American Society for Microbiology, Proceedings of the 2nd International Symposium, Washington, DC, 1984

3) Black and Veatch, A Guide to Water Conservation For Cooling Towers, Los Angeles Department of Water and Power, Los Angeles, CA, 1991

4) Nalco Chemical Co., Operator Training Manual ADV444, Nalco Chemical Co., Oakbrook, IL, 1992

5) Nalco Chemical Co., Program Administration Manual ADV194, Nalco Chemical Co., Oakbrook, IL, 1979

6) Westway C., Loomis A., Cameron Hydraulic Data 16th Ed., Ingersoll-Rand, Woodcliff Lake, NJ, 1984

7) Crane Co., Flow of Fluids Through Valves Fittings and Pipes, Crane Co., Chicago, IL, 1976

8) ASHRAE, Heating, Ventilating, and Air-Conditioning Systems and Applications, Atlanta, GA, 1987

9) Smithers J., Annual Energy and Water Conservation Report FY 91-92, UCLA Facilities Management Energy Services, Los Angeles, CA, 1993