UPDATED PROJECT REPORT

DEMONSTRATION OF WATER CONSERVATION OPPORTUNITIES IN URBAN SUPERMARKETS

July 21, 2004

Submitted to:
Metropolitan Water District of Southern California
California Department of Water Resources/U.S. Bureau of Reclamation
CalFed Bay-Delta Program

Submitted by:
Aquacraft, Inc. Water Engineering and Management
2709 Pine St.
Boulder, CO 80302

Table of Contents

List of Tables

List of Figures

EXECUTIVE SUMMARY

This study investigated the potential water savings of advanced water treatment on typical urban supermarket cooling systems. Water use patterns in the remainder of the store were also investigated as a secondary subject. The goal of the study was to quantify the water saving potential and the economic feasibility of advanced water treatment in cooling systems, and to look for water saving opportunities in the other water uses in the stores.

This study was made possible by a grant from the California Department of Water Resources and the financial support and co-operation of the Los Angeles Department of Water and Power, the City of Santa Monica, the Upper San Gabriel Water District, the Eastern Municipal Water District and the Irvine Ranch Water District. A follow-up grant from the Metropolitan Water District of Southern California was awarded in 2003, which allowed the study to continue through the end of the year. This report has been updated to include this additional information.

The sites included in this study were all typical full-service type urban supermarkets operated by companies such as Ralph's, Stater Brothers, Albertson's and Vons. For confidentiality purposes none of the precise stores are identified, but they are referred to according to their location: Arcadia, Beverly, Irvine, Santa Monica, Sun City and USC. These stores were typically 50,000 sf in size and had multiple departments. Some had full kitchens and food preparation areas and other had minimal food preparation. All had some form of meat, produce, bakery and service deli, and all used water cooled evaporative condensers to cooler their refrigeration systems.

The baseline water use characteristics of the stores are shown in the Table ES-1. These stores, which were chosen at random, used an average of 3.5 million gallons of water per year, which was split nearly 50:50 between cooling use and other in-store uses. Daily cooling use and in-store uses equaled approximately 4,100 gpd. It was also found that the cooling use of the stores was split between evaporation and bleed such that evaporation accounted for approximately 2400 gpd and bleed used 1700 gpd. The average concentration ratio of the cooling systems during the baseline period was approximately 2.45.

Table ES-1: Summary of baseline water use in 6 study stores (kgal)

	ARC	BEV	IRV	SC	SM	USC	Average
Water Meter Data							
Annual Use	2244	5064	4044	1908	4512	3408	3530
Ave Month	187	422	337	159	376	284	294
Ave Day	6.15	13.85	11.25	5.3	12.53	9.48	9.76
Daily Use During Logging							
Total Daily Use	4.924	9.047	10.734	5.389	12.447	8.948	8.582
In-Store Use	1.313	4.596	6.867	2.357	5.033	4.601	4.128
Total Cooling Use	3.61	4.451	3.867	3.032	5.431	4.347	4.123
Bleed	0.973	1.283	1.547	1.399	3.026	1.859	1.681
Evaporation	2.638	3.168	2.23	1.633	2.404	2.489	2.427

The energy use at the stores was examined because there is a close link between energy use and cooling at these stores. It is well known that a cooling system that has scale problems will use more energy for refrigeration than one with clean condenser tubes. The baseline energy use for the stores is shown in Table ES-2. On average, these stores use over 2.3 million kWh per year, which is a significant amount of energy consumption. At $.06/kWh this comes to an annual power bill of $138,000.

Table ES-2 : Baseline energy use at study sites

2001	Sun City	Irvine	Arcadia	Beverly	USC	Average
Total Annual (kWh)	1,671,120	3,295,477	1,421,174	2,919,168	2,333,280	2,328,044
Avg. Month (kWh)	139,260	274,623	118,431	243,264	194,440	194,004
Std. Dev. (kWh)	8,704	23,348	9,022	16,025	15,822	14,584

Essential to any cooling system analysis is a discussion of the basic concepts of cooling water use in relationship to the cycles of concentration of the water in the cooling systems. Two key relationships between cycles of concentration and bleed water use are presented. The first is the definition of concentration ratio as the ratio between the total make-up water and the bleed water, or CR = M/B. This tells us that as long as the amount of bleed water is proportional to the amount of water entering the system the concentration ratio will remain constant irrespective of variations in the inflow water chemistry. The other relationship is that the water used for bleed will vary inversely with the concentration ratio, such that B = E/(CR-1), where E is the water lost to evaporation. This tells us that it is physically impossible to ever achieve a concentration ratio of 1, since to do so would require an infinite amount of water. It also shows that as the concentration ratio increases the reduction in bleed water use diminishes, which can be seen in Figure ES-1. As the cycles of concentration exceed 5.5 or 6, however, the reduction in total water use becomes negligible.

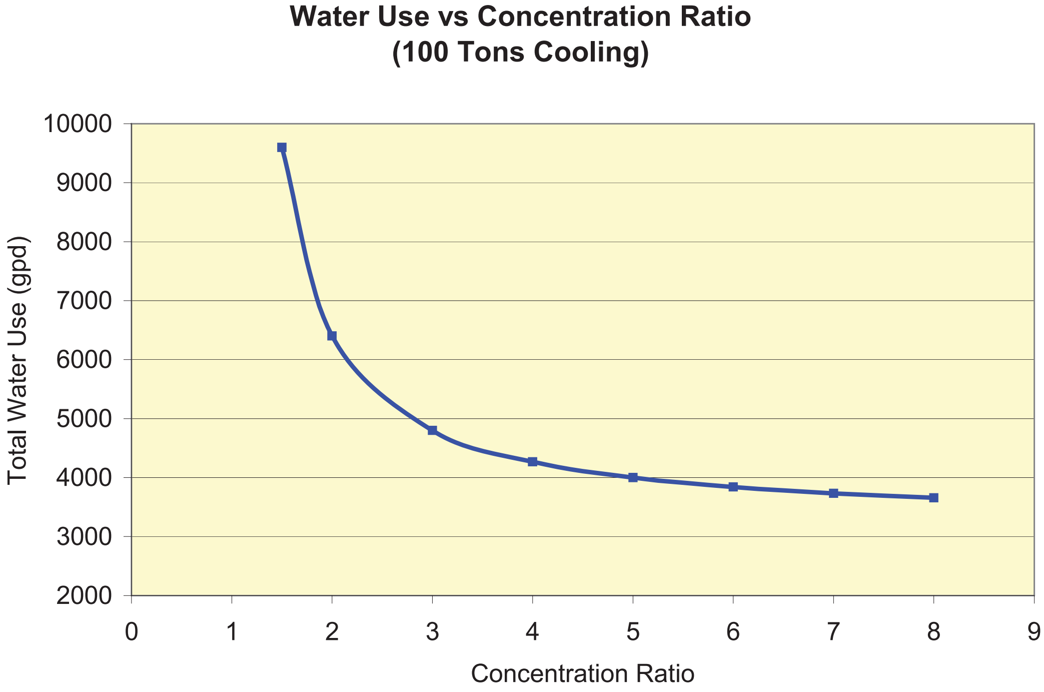


Figure ES-1: Cooling water use versus concentration ratio.

This report also discusses the critical elements of water treatment in evaporative condensers. The major concern is the prevention of scale as the concentration of minerals in the system increases. The primary scale mineral is calcium carbonate (calcite), which is formed when calcium and carbonate alkalinity ions react. The result is an insoluble deposit of calcium carbonate on the tubes and internal surfaces of the system. Because calcium carbonate is so insoluble this reaction occurs whenever the carbonate ion is the primary form of alkalinity present in the water. This is the situation when the pH in the system exceeds 8.3. Conventional water treatment normally operates at pH levels of 8.8 or higher, but it aims to retard the scale formation using chemical threshold inhibitors. These will delay scale formation, but will not prevent it. Advanced water treatment, such as alkalinity control, makes calcium carbonate formation impossible by keeping the pH below the 8.3 threshold, where the primary alkalinity ion is the bicarbonate ion, which is soluble with calcium.

Caution should be used, since even if calcium carbonate formation is prevented there are a wide range of other scale forming minerals that can precipitate onto the pipes. These can include the very chemicals that are being added to prevent scale formation in the first place, if they are overdosed! Important scale minerals that need to be watched for include calcium sulfate (gypsum) which can form whenever the concentration of calcium and sulfate exceed critical levels. This is a serious concern in systems that are using sulfuric acid (H_2SO_4) for alkalinity control. Calcium phosphate and calcium phosphonate are also concerns since phosphates and phosphonates are frequently used for scale and corrosion inhibitors. Also, many municipal water supplies may contain measurable amounts of phosphorous, which can add to the scale potential. Magnesium silicate is an especially difficult scale to remove, and is of concern where the feed waters are high in silica.

Besides scale formation, the two other water management problems in evaporative condensers are biological fouling and corrosion of the copper and steel metals they contain.

There are a wide range of chemicals used to control scale, corrosion, and biological fouling. The treatment is complex since chemicals which may be used for one problem without incident may react with others used for other reasons, and this reaction my create a scale or corrosion problem that would not be predicted by use of either chemical alone. An example of this would be the use of chlorine for biological control reacting with phosphonates to release phosphate, which then combines with calcium to form calcium phosphate scale.

The key to a successful water treatment program is in having an experienced water treatment contractor with trained chemists supervising the program and performing periodic testing and observations.

Three water treatment technologies were investigated in this study. Two of the six study sites were used for each system. The Zeta Rod, tested at Sun City and USC, uses static electricity to induce a strong similar charge on the scale particles in an attempt to keep them in suspension and from accumulating into a solid scale formation. This is a form of electrical dispersion, and parallels certain chemical processes, which seek to do the same thing with chemical agents.

The Scale Viper was tested at Arcadia and Beverly. This is a system that uses pulsing electromagnetic radiation to modify the crystal formation process and allow the hardness minerals to precipitate out of solution as a harmless aragonite powder, which can be removed from the sump during routine cleaning.

As part of the MWD sponsored follow-up study two stores in the Scramento area which used the Dolphin system of electro-magnetic pulsed power were visitted. Both of these stores were being operated with no chemicals and no scale at cycles of concentration from 4 to 5. This was encouraging, however, we were not able to find a store using Dolphin technology that was operating scale free at the higer mineral concentrations found in southern California. Since the technology is promising, however, it is hoped that others will follow-up with detailed field studies.

The third process was the chemical process of alkalinity control, which uses a feed of sulfuric acid in combination with various corrosion preventers to neutralize alkalinity in the circulating water and keep the pH below 8.3, the inflection point between calcium bicarbonate and calcium carbonate. By keeping the pH below 8.3 the concentration of calcium carbonate is kept low, carbonate scale formation is prevented.

The results of the test showed that while each of the systems has some drawbacks, only the alkalinity control program was able to successfully operate at higher cycles of concentration without causing either scale or corrosion to the system.

The Zeta Rod and Scale Viper system did not prove capable of staying ahead of the scale at the concentrations found in these systems. All four of the test sites that used these systems developed aggressive scale formations within 30 to 60 days of the start of the test. These systems were discontinued, and one of the sites, Beverly, was converted to alkalinity control.

Of the three systems using alkalinity control all operated at cycles of concentration of 5.5 or more and none experienced calcium carbonate scale. Also, the corrosion rates were excellent in all three sites. By August, however, after nearly 10 months of operation, a soft scale had begun to appear on two systems using chemicals from the same supplier. These were tested and showed high levels of phosphate in the scale. Steps were being taken to eliminate these problems as of the date of this report.

The water savings achieved at the six sites exceeded the amounts predicted by the theoretical calculations. This is probably because the actual change in cycles of concentration was greater than those assumed in the calculations. The amount of water saved at each site is shown in Table ES-3. This shows that on average, the shift from conventional to advanced treatment resulted in savings of 709 kgal per year (948 ccf). The least amount of water saved was 496 kgal per year at Irvine, and the greatest savings were 1072 kgal at Santa Monica. These savings were exclusively from the changes to the cooling operations, and were measured using the water meters on the cooling systems themselves.

Table ES-3 Water savings at six study sites

Store	Savings (gpd)	Kgal/month	Kgal/year
Arcadia	2135	65	781
Beverly	1714	52	627
Irvine	1354	41	496
Santa Monica	2930	89	1072
Sun City	1641	50	601
USC	1844	56	675
Average	1936	59	709

The benefits derived from an advanced water treatment program are threefold: 1. A reduction in water use and lowered water and wastewater charges; 2. Reductions in electrical use due to less scale on the tubes and lower energy requirement for cooling; and 3. The ability to reduce the amount of acid washing required to keep the system scale free, and with it the extension of the life of the cooling tube bundle and side walls.

An economic evaluation of the system was conducted assuming each used the same alkalinity control program and achieved the savings that were observed at each site during the test. Costs of installation and incremental operations were included. Benefits from reduced water and wastewater, a 5% reduction in electrical consumption and avoidance of a major overhaul in year 15 of a 25-year life cycle were included. All costs and benefits were brought back to a present worth using a discount rate of 5%. The results of this analysis are shown in Table ES-4.

It is noteworthy that four of the six sites showed a strong benefit to cost ratio for conversion to alkalinity control using only the savings in water and wastewater on the benefits side of the equation. The two sites that had ratios less than 1 both had unusual rate structures. In Sun City that had the lowest ratio (0.8) they do not charge for wastewater on a unit consumption basis, so there were no savings to be credited from reductions in wastewater flows. In the other, Irvine, which had a ratio of 0.95 they are using a fairly new water budget system, and the allocations they have provided to the supermarkets appear to be too generous, since they cover all of the water use at the store, under the conservation rate, even though it is known that there is ample room for conservation at this store.

Table ES-4: Economic analysis of alkalinity control program

Store	Water Savings	Combined Rates	Baseline Energy Use	Savings Present Worth $				Cost PW	Ben/Cost Total	Ben/Cost Water
	kgal		kWh	Water/WW	Energy	Maint	Total			
Arcadia	781	$5.14	1,421,174	$69,876	$74,213	$24,051	$168,139	-$26,946	6.24	2.59
Beverly	627	$5.60	2,919,168	$61,118	$152,437	$24,051	$237,606	-$26,946	8.82	2.27
Irvine	496	$2.97	3,295,477	$25,642	$171,819	$24,051	$221,512	-$26,946	8.22	0.95
Santa Monica	1072	$5.67	2,500,000	$105,801	$130,848	$24,051	$260,700	-$26,946	9.67	3.93
Sun City	601	$2.06	1,671,120	$21,550	$88,156	$24,051	$133,758	-$26,946	4.96	0.80
USC	675	$5.60	2,333,280	$65,797	$122,261	$24,051	$212,108	-$26,946	7.87	2.44
Average	709	$4.51	2,356,703	$58,297	$123,289	$24,051	$205,637	-$26,946	7.63	2.16

All of the other sites which had more traditional rate structures showed benefit cost ratios for conversion to alkalinity control of 2.16 or more, and the maximum site, Santa Monica, had a ratio of 3.93. If allowances are made for reasonable savings on electricity and avoided maintenance then the benefit cost ratios rise dramatically. In this case the lowest B/C ratio is nearly 5 and the highest is nearly 10.

The conclusion of this study is that a well run alkalinity control program can pay for itself in one or two years, and that over the life of a new evaporative condenser the benefits from using advanced water treatment will be between 2 and 10 times the incremental costs of using the system.

Recommendations for other in-store water savings included the use of high efficiency spray nozzles, aerators, and water flow restrictors on all hand sinks and spray tables. Another recommendation would be for the elimination of garbage grinders in favor of composting produce wastes, as well as replacement of low pressure hoses with high-pressure sprayers and even simple mops and buckets for washing the meat department. All of the stores in this study already had ULF toilets and urinals, but these would be the first step in stores that don’t already have them. Finally, the development of an education program that encourages employees to report leaks and wastage and rewards them for conserving water is an essential step in obtaining support and co-operation of the employees.

It seems reasonable that with an aggressive campaign of cooling and in-store conservation it should be possible to save over 800 kgal (1069 ccf) per year on average per store, which is nearly 2.5 acre feet per store. These are the kinds of savings that could add some major volumes if applied to the entire southern California area. Hopefully future work will confirm this, and the recommendation of the study will be adopted by the industry.

INTRODUCTION

The State of California has focussed increasing attention on the need to conserve water in all areas of its economy. There are several factors that have led to this situation, but the two most visible factors have been the settlement between the State and the U.S. Government on the status of the San Francisco Bay Delta protection and the curtailment of water diverted from the Colorado River by the Department of Interior.

In April of 1998, the California State Water Resources Control Board signed a memorandum of understanding with the major municipal water providers that relied on water exported from the Sacramento/ San Joaquin rivers above their confluence with the San Francisco Bay. This agreement is referred to as the Bay/Delta agreement. One of the key elements of the agreement is that each of the signatories promised to make good faith efforts to implement a series of Best Management Practices for water conservation. This created an obligation on the part of the water providers to implement water conservation within their service areas in a significant way, rather than as merely a vague goal towards which each was to strive.

The Bay/Delta agreement dealt with a major supply of water for Southern California from the north, and pointed out the finite nature of this supply. At the same time, circumstances surrounding another critical supply, the Colorado River became more complicated. The Colorado River Compact, signed in 1929, governs use of the Colorado River. Under the terms of this compact, California was entitled to use up to 4.4 million acre feet of water from the river. In recent years, however, the state has used up to 5.2 million acre feet. Historically, this practice was not a problem since many of the other 6 entities that use the river were not using their full entitlement, but as these parties increase their use it has become obvious that California cannot continue to overdraw its account. In December of 2002, the U.S. Secretary of the Interior signed an order limiting the amount of water California can withdraw from the Colorado River, marking the first time that the Department of Interior has acted to reduce the 800,000 acre foot gap between California’s actual water use and its agreed limits of 4.4 million acre feet of withdrawals from the Colorado River.

These dual events served as a wake-up call for all municipal water users in California on the need to make real efforts to conserve water in their systems and to encourage the best and most efficient use of water by their customers. Combined with the risk of drought and an ever-growing population, the situation in California has never been more favorable from the perspective of water management and water conservation.

Acknowledgments

This project was conducted with the support of the California Department of Water Resources in conjunction with five water providers from the Metropolitan Water District of Southern California. These included: the Upper San Gabriel Water District, servicing Arcadia; the City of Santa Monica, the Los Angeles Department of Water and Power, Irvine Ranch Water District, serving the City of Irvine, and Sun City.

The Metropolitan Water District of Southern California supplied additional funding to track the project through the end of 2003, which allowed additional information to be obtained on the impacts of abandoning alkalinity control systems and on the Dolphin water treatment system.

In addition, the project would not have been possible without the support and cooperation of the supermarkets companies: Ralphs Grocery Company, Vons (Safeway), Stater Brothers and Albertsons. The exact locations of the stores and identities of each store are being kept confidential, but these companies provided sites for the studies and allowed us to use their evaporative condensers as test subjects. They also provided access to their water and power consumption records and allowed the research team with access to all areas of the store to conduct water use evaluations.

The researchers also wish to express our appreciation to the manufacturers who provided test equipment for the study in order to determine its effectiveness for water treatment in evaporative condensers. The Zeta Corporation provided Zeta Rods for two stores and Tellco provided the Scale Viper system for testing in two stores.

Each of the stores in this study had a water treatment contractor that provided service to the cooling systems. These contractors also co-operated with the study by using the test equipment as directed by the manufacturer, monitoring the results and communicating their observations with Aquacraft. The McMillan Water Treatment Company provided service to four of the sites, the Chem Pro and Uni-Chem Companies each provided service to one site.

Mr. John Medina, of Water in Motion and Mr. Fernando Salvador of Tri-Chem Technologies provided support and management for the alkalinity control treatment studied at

the Irvine and Santa Monica sites, and Bill Snyder, of Chem-Pro Labs provided this service at the Beverly site after the initial test equipment being studied there was removed.

This project required the support of all of the above parties, and the researchers wish to thank each of them for their contributions.

Background of Project

The origins of this project lay in the Commercial and Institutional End Uses of Water Study (CIEUWS) (Dzieglielewski, et al.), which was published in 2000. That study identified supermarkets as one of the five most significant commercial water users in most urban water systems. This was based on the amount of water typically used at each store and the overall percentage of municipal water that supermarkets as a category account for.

In the CIEUWS, the water use of supermarkets were examined from both a macro level through means of billing data and from a micro level through a series of site visits and data logging efforts. The field visits were conducted in five cities in the Southwest including Los Angeles, San Diego, and Denver. This resulted in some overall characterization of the range of water use in urban supermarkets and the end uses to which water is applied at these sites.

The two main conclusions of the CIEUWS were that, first, supermarkets are consistently among the most significant users of water within the Commercial/Institutional category of customers, and second, the largest water use in supermarkets is for cooling the refrigeration system. Typically, water for cooling was found to comprise half or more of the total water use at each store. A critical conclusion on cooling use was also reached, namely that these systems are typically not operated to minimize their water use. On the contrary, most coolers are operated in a way that maximizes their water use in an effort minimize the cost of water treatment.

These results suggested that it would be a good idea to take a closer look at water use in municipal supermarkets from the perspective of water resource management. In 1991 Aquacraft and the five municipal providers applied for a grant from the California Department of Water Resources to conduct a study of the potential for water conservation in supermarkets, focussing on better operation of their cooing systems. This project was funded by CDWR and work began in the summer of 2001. This report provides documentation of the findings of the study with conclusion and recommendations for future research and practical implementation of best management practices for the California Urban Water Conservation Council.

Goals

The main reason why most cooling systems are operated with high rates of bleed is that their operators are afraid of scale formation on the internal piping in the system. The goals of this study were to investigate three technologies that were represented by their proponents as having the capability of allowing the cooling systems in supermarkets to operate at higher cycles of concentration (to be explained later) without resulting scale or corrosion problems. A secondary area of investigation was the opportunities for conservation in the other water using operations of the stores.

Both water and energy data were collected for each store so that baseline and post retrofit consumption patterns could be investigated.

DESCRIPTION OF STORES

The Safeway Company - owner of the Vons stores, the Kroger Company, owner of Ralphs Grocery Company, Albertsons, and Stater Brothers, provided the stores included in this study. All of these companies are major supermarket operators in the Southern California area as well as in the rest of the United States. The study included three Ralphs stores and one from each of the other companies, for a total of six stores. In order to maintain some confidentiality none of the specific stores will be identified by owner, but will be referred to by either their location or a short alphabetical code so they can be identified easily in tables and graphs. Some of these stores were included in a previous study conducted by Aquacraft, Inc. for the AWWA Research Foundation (AWWARF) called, Commercial and Institutional End Uses of Water.[1]

Nomenclature

Before getting involved with descriptions of individual stores it would be useful to define some terms as they are used in this report concerning water using fixtures and cooling water technology. Several names for water using devices have special meaning in the grocery store setting, and the researchers want to be clear on references to the devices found in the stores. Any fixtures or terms not included in this glossary simply have their normal meaning.

Table 5: Glossary

Term	Description
Alkalinity	a measure of all chemical compounds in water that react to neutralize acids, predominantly bicarbonate ion (HCO_3^-) in municipal water systems
Bleed water	water bled from cooling system to sewer system to carry away dirt and dissolved solids. Also called blowdown.
Bleed water meter	a meter on the bleed line from the cooler
Closed loop cooler	a device that uses a closed loop of water to cool the refrigerant in a heat exchanger rather than running the refrigerant through the cooler in tube bundles
Compressor	electrically driven compressors that condense refrigerant, typically 10-25 hp each
Concentration Ratio	the ratio of the concentration of a parameter in the recirculating water to the make-up water. It is also the ratio of the feed water volume to the bleed water volume over a period of time.
Conductivity	a measure of the electrical conductivity (µmhos) of water that relates to its dissolved solids level. It is the inverse of resistance.
Cooler	general term used to denote either an evaporative condenser or a closed loop cooler
Tube bundles	pipes that carry either refrigerant or closed loop cooling water through the recirculating water stream
Cooling water use	all water used by the coolers for evaporation and bleed
Corrosion	a physical or chemical process that dissolves metal from the cooler tubes and walls
Evaporation Water	water evaporated to the atmosphere for cooling purposes
Evaporative Condenser	a mechanical device that uses recirculating water to cool refrigerant directly
Faucet, Food Sink	faucet used to prepare food, often used continuously with large sinks
Faucet, Pot Sink	used to fill a multi-compartment sink for pot or dish washing, usually volume driven
Faucet, Hand Sink	faucet used specifically for hand washing. May have either manual or knee activated valves
Garbage grinder	A large machine that grinds produce waste for disposal to sewer
Hand Sprayer	hand activated sprayer at either a food prep or pot washing sink.
Hardness	the concentration of bi-valent metal ions in solution (predominantly Ca^{+2}, Mg^{+2}). These are key components of scale. Hardness and alkalinity are expressed in terms of mg/l of Calcium Carbonate ($CaCO_3$)
Hose, high pressure	a high pressure hose used for washing food prep areas, containers and utensils
Hose, standard	a low pressure garden type hose used to wash and disinfect food prep areas
In-store use	water used for all purposed inside the store, except for cooling.
Line sharing device	a device that allows one telephone line to be shared by several voice or data lines
Main meter	a water meter on the main water line to the store

Term	Description
Make-up water	water used to feed the cooler to replace evaporation and bleed
Make-up water meter	a meter on the water line supplying the evaporative condenser or closed loop cooler
Modem	a telephone modem connected to the programmable controllers for remote data logging and control.
pH	the standard chemical measure of alkalinity or acidity of water.
Programmable controller	a computer like system for control of cooler bleed and chemical feed from conductivity and pH sensors, as programmed by user.
Recirculating water	water inside the coolers that recirculates over the cooling tubes
Scale	a mineral precipitate on the internal pipes and walls of the cooler
TDS	total dissolved solids (milligrams per liter, mg/l)
Corrosion coupon	a metal sample exposed to recirculating water to obtain a direct measure of corrosion rates (copper and steel)

Arcadia (ARC)

The Arcadia store is approximately 45,000 sf in size, and is located in the northeast part of the Los Angeles metro area, in the town of Arcadia, at the foot of the San Gabriel Mountains. An initial site visit for this study was made on November 16, 2001. This is a fairly simple store with limited in-store services and water using devices. There is no on-site cooking or baking except for limited food preparation at the service deli. It has a meat department and a produce department but no bakery or pharmacy. The produce department has no garbage grinder and all of the produce waste is hauled away for composting. There are four bathrooms in the store: 2 for the staff upstairs and 2 for the public downstairs. There is a 1/5" Neptune water meter that serves the store. There is no irrigation demand through the meter so all of the water used is for in-store or cooling purposes. This meter is located on 2nd Avenue to the east of the store and has the number 31,641,901 stamped on its cover.

The refrigeration system is cooled by a Frigid Coil evaporative condenser that was newly installed in July 2001. The cooler is rated at 120 tons and there was a meter on the make-up line at the start of the study so that the cooling water use could be recorded. This meter provided 2 pulses per gallon of inflow. The store has 14 compressors in its mechanical room with a total rating of 125 horse power (hp).

At the initial visit, the bleed from the cooler was controlled by a flow proportional controller attached to the pulsing meter. The controller was set to open the bleed valve for 3 minutes for every 55 gallons of inflow. Chemicals for scale prevention and corrosion control were being fed to the cooler by gravity. McMillan Water Treatment was providing the service and the chemical compound they were using was labeled as C8022, which is a proprietary mix of poly-phosphates for scale control and other chemicals for corrosion control. The concentration ratio of the system on the day of the initial visit was only 1.28 because the tank was overflowing due to a stuck valve (a fairly common problem in these systems).

The quality of the water supplied by the Upper San Gabriel water district is one of the best in the study. On our initial visit the water was moderately hard, at 180 mg/l and the alkalinity was 170. The total dissolved solids was 280 mg/l and the conductivity was 375 μ mhos.

Table 6 shows the number of fixtures found in the store. Note that there are no dishwashers or ice machines in the store, nor is there a garbage grinder in the produce department.

Table 6: Fixtures and appliances at Arcadia Store

Fixture	Number present	Comments
Hand Sinks	9	4 in bathrooms upstairs for staff and downstairs for public. Three in store have foot controls. None have low flow aerators.
Food Sinks	1	In meat dept. Feeds a hand sprayer.
Pot Washing Sinks	5	Meat, produce, deli. Floor sprayers are fed from faucets of some.
Hose bibs/Sprayers	2	In meat dept. and deli
Urinals	1	Mens room upstairs
Tank Toilets	0	
Flushometer Toilets	4	In bath rooms, 1.6 gpf
Garbage grinder	0	They compost their produce waste
Evaporative Condenser	1	Frigid coil YEC-5-120, 2001
Total	23	

Beverly (BEV)

The Beverly store is approximately 45,000 sf in size and is located in Los Angeles. This store has more water using devices than does the Arcadia store. In addition to the produce department and a meat department, the store has a bakery and a Chinese café. The café has three woks which each have a faucet over them for cooking and rinsing food. These faucets are often left on continuously during cooking and use a significant amount of water. The bakery uses pre-mixed batters for most of its breads and cakes, but requires water for washing pots and pans and general clean-up. The initial visit to the store was made on November 13, 2001.

The store is served by a 1.5" Neptune meter that is in the bushes on the east property line behind the store on Beverly Blvd. There is no irrigation water use served by this meter. The meter number is 81,572,175 and is owned by the Los Angeles Department of Water and Power. Table 7 shows the fixtures and appliances present in the store.

The evaporative condenser for the refrigeration system is a 200-ton Frigid coil unit with a pulsing water meter on the inflow line. This meter gives one pulse per 50 gallons of inflow. At the time of the initial visit to the store the bleed system was controlled by a proportional controller set at 3 minutes of bleed for every 50 gallons of inflow. The water treatment for this site was provided by the ChemPro Laboratories, Inc. They were using polyphosphate anti-scale chemical and bromine for biocide. The target was 3 cycles of concentration, but on the day of the initial visit the actual concentration ratio was only 1.3 due to an overflow problem in the tank. The system has 16 compressors with a rated output of 120 hp. This is the lowest compressor output of the stores.

Water supply for this store is from the Los Angeles Department of Water and Power. On the day of the initial visit (in November) the water was fairly good with a conductivity of 340, alkalinity of 65 mg/l and total hardness of 120 mg/l.

Table 7: Fixtures and appliances at Beverly

Fixture	Number present	Comments
Hand Sinks	11	5 in bathrooms, rest scattered in depts. A couple of hand sinks have knee controllers. Flow rates 2-3 gpm
Hand sprayers	3	Flow rates 2 to 3 gpm
Food Sinks	4	3 in wok station. 9 gpm each
Pot Washing Sinks	6	In various depts. Some have sprayers fed from same feed lines that supply the sink. 9 gpm
Hose bibs/Sprayers	4	For floor sprayers and disinfection units. 7 gpm
Urinals	4	Low consumption
Tank Toilets	0	
Flushometer Toilets	3	1.6 gpf in men (1); 3.5 in women (2)
Other		Misc. ice machines, produce misters, etc.
Garbage grinder	0	No grinder.
Evaporative Condenser	1	Frigid coil, YEC-6-200 (1999)
Total	36	

Irvine (IRV)

The Irvine store is approximately 38,000 sf in size. The store contains a service deli, meat/seafood dept., produce dept., and bakery. Water for the store is metered through a 2" Neptune T10 water meter located behind the store. There is no irrigation water delivered through this meter. This is a fairly standard store with no restaurants or major food preparation activities on site. Observation showed that one of the major in-store water uses is for washing the meat department, which occurs between 1:00 and 4:00 PM. A garden hose with a hand sprayer is used for this and the process uses a significant amount of water (more detail is provided in the baseline water use section of the report).

The cooling system in this store includes of a Recold 200 ton evaporative condenser, which was installed in 1989. At the time of the initial visit the cooler was being operated using conventional scale and corrosion control chemicals at 3 cycles of concentration. The conductivity of the inflow water was 450 µmhos, the alkalinity was 220 mg/l and the total hardness was 90 mg/l. There was a pulsing meter on the inflow line and a proportional controller controlled the bleed. There are a total of 12 compressors on the system with a rated output of 135 hp.

Table 8: Fixtures and appliances at Irvine

Fixture	Number present	Comments
Hand Sinks	6	Most flowing at 4-5 gpm
Hand sprayers	4	1 and 3 gpm
Food Sinks	6	7 gpm
Pot Washing Sinks	3	7 gpm
Hose bibs/Sprayers	3	One high-pressure in meat dept.
Urinals	1	Low consumption
Garbage grinder	1	Used 5 hrs per day at 5 gpm
Flushometer Toilets	3	All 1.6 gpf
Evaporative Condenser	1	Recold JC-200 (1989)
Total	28	

Santa Monica (SM)

The Santa Monica store contains a service deli, meat dept., bakery, produce department, and pharmacy. Except for the deli there is no cooking in the store. The bakery only bakes, it does not mix or use much water for food prep. Water for the store is metered by a 2" Badger meter, number 82,158,184, which is located above ground in front of the store on Cloverfield. This is the only store that has irrigation water delivered through the meter, which complicated obtaining an accurate measure of the water use pattern inside the store.

The cooler is a Frigid Coil 240 ton evaporative condenser. On the day of the initial site visit, on November 14, 2001, the system was being operated at approximately 3 cycles of concentration. A proportional controller set to bleed for 3 minutes of bleed for every 50 gallons of inflow controlled bleed. The conductivity of the inflow water was 600 µmhos, the alkalinity was 150 mg/l and the total hardness was 220 mg/l. There are a total of 16 compressors with rated power of 205 hp. This is the largest compressor power output of any of the stores in the study.

Table 9: Fixtures and appliances at Santa Monica

Fixture	Number present	Comments
Hand Sinks	13	4 in upstairs bathrooms, 2 in down stair bathrooms; rest scattered in depts. Most flowing at more than 2.5 gpm. Missing aerators.
Hand Sprayers	7	Most flowing at 4-6 gpm
Food Sinks	4	7-8 gpm. Could use swivel sprayers.
Pot Washing Sinks	5	In various depts. Some have sprayers fed from same feed lines that supply the sink.
Hose bibs/Sprayers	2	For floor sprayers and disinfection units. Both low pressure garden hoses.
Urinals	1	Standard flush
Tank Toilets	1	In pharmacy (1.6 gpf)
Flushometer Toilets	5	All ULF
Garbage grinder	0	No grinder.
Other		Misc. ice machines, produce mini sprayers etc., nothing major
Evaporative Condenser	1	Frigid Coil YEC-7-240
Total	39	

The City of Santa Monica provides water for the store. On the day of the initial visit, the inflow water was found to have a pH of 8.4, a TDS of 410 ppm, alkalinity of 150 mg/l and a total hardness of 220 mg/l. The cooling system was operating at a concentration ratio of 3.2. There was a water meter on the inflow line to the cooler, but not on the bleed line.

Sun City (SC)

The Sun City store is located in the service area of the Eastern Municipal Water District. The initial site visit was made on November 15th, 2001. This store has a fairly simple set-up consisting of just a meat and produce department and a small service deli. There is no on-site baking, nor is there a garbage grinder in the produce department.

The cooler for the store is a Recold 80-ton fluid cooler that uses a closed loop cooling system to cool refrigerant in heat exchangers. The tube bundles in the tower carry the closed loop cooling water between the tower and the heat exchangers. This is the only store that has this type of cooler, and at 80 tons, it is also the smallest rated capacity of any of the coolers. There are 13 compressors in the mechanical room with a total rated output of 122 hp. The circulating water in the cooler flowed through a 2” PVC pipe

The cooling tower did not have a water meter installed on its bleed line at the initial visit, and the main structural walls of the tower showed a lot of corrosion. The tube bundles, however were in good condition and showed little scale or corrosion. Based on conductivity readings, the tower was running at approximately 3 cycles of concentration. The bleed was controlled by a conductivity controller set to bleed at 2000 μmhos, which would typically result in 3 cycles of concentration.

As shown in Table 10, there are a relatively low number of water fixtures and appliances in this store. The toilets and urinals were all standard consumption models. The faucets had a range of aerators, most of which used significantly more than 2.5 gpm and some were missing aerators altogether. With the absence of a garbage grinder, the main water using fixtures in the store were the cooler and the hose bib used for cleaning the meat department. These were followed by the pot sinks and hand sinks. With only 15 fixtures, this store contained the least water using devices.

Table 10: Fixtures and appliances at Sun City

Fixture	Number present	Comments
Hand Sinks	5	Throughout store dept.
Food Sinks	2	In meat and produce
Pot Washing Sinks	2	In meat dept.
Hose bibs/Sprayers	1	In meat dept.
Urinals	1	Mens room, standard consumption
Tank Toilets	0	
Flushometer Toilets	3	In bathrooms, standard
Garbage grinder	0	Grinder was removed
Evaporative Condenser	1	Recold 80, closed loop cooler
Total	15	

USC (USC)

The USC store is located just north of the University of Southern California in the service area of the Los Angeles Department of Water and Power. It is served by a single water meter that is located on the east side of the store on Menlo Street. The meter is a 2” Neptune T10, with number 49244150 stamped on the cover. No irrigation water is delivered through this meter.

The USC store contains a service deli, meat dept., bakery and produce dept. Except for the deli there is no cooking in the store. The bakery only bakes, it does not mix or use much water for food prep. The produce department in this store has a garbage grinder, making it and the Irvine store the only two stores with grinders.

The cooler for the store is a Frigid Coil 285 ton evaporative condenser. The cooler was being treated with conventional scale and corrosion control chemicals at approximately 3 cycles of concentration. There was a water meter on the inflow line to the cooler, but this store like all of the others did not have a meter on the bleed line. None of the water treatment companies liked placing meters on the bleed lines since the grit, dirt and debris in the bleed water tends to plug up the meters. Placing a strainer on the bleed lines gives them concern since this adds another place for the line to get plugged, and anything that cuts off the regular bleed threatens to damage the tower with scale. The cooler serviced 16 compressors with 160 rated horsepower.

Table 11: Fixtures and appliances at USC Store

Fixture	Number present	Comments
Hand Sinks	8	4 in bathrooms, rest scattered in depts Most hand sinks have knee controllers
Hand Sprayers	3	Meat, deli and produce depts.
Food Sinks	2	
Pot Washing Sinks	5	In various depts. Some have sprayers fed from same feed lines that supply the sink.
Hose bibs/Sprayers	3	For floor sprayers and disinfection units
Urinals	1	
Flushometer Toilets	3	1.6 gpf
Garbage grinder	1	In produce. 6 gpm used 4 hrs per day.
Other		Misc. ice machines, produce mini sprayers, etc.
Evaporative Condenser	1	Frigid Coil YEC-7-285
Total	27	

STUDY PROCEDURES

The proposal for this study was entitled, “Demonstration of Water Conservation Opportunities in Urban Supermarkets”, and was submitted to the California Department of Water Resources on February 14, 2001. This proposal identified cooling systems as the main target of the study. The intent of the study was to investigate three technologies that promised to allow the coolers to operate at higher concentration ratios, and which had been approved by the Los Angeles Department of Water and Power for reimbursement under their Technical Assistance Program. In addition, the other water using devices in the store were to be evaluated to estimate their relative use of water and their potential for water conservation.

The project was approved during the Spring of 2001, and contracts were signed with the supermarket owners during the Summer and Fall of 2001. The initial visits to the stores were conducted in November, 2001 after all of the contracts were signed.

Water savings were then to be linked to monetary savings at each store from reduced water and wastewater bills and an economic evaluation prepared showing the present worth of the benefits from retrofits against the comparable costs. The main goal of the project was to identify viable technologies for water conservation and to accelerate their adoption by the industry.

The steps in the work plan consisted of the following:

1. Study Site Selection. Each participating utility obtained the permission of one store (except for Los Angeles which obtained 2) to act as study sites for the project. A total of six stores were selected. Contracts were signed with the owners to allow the use of the stores. It took until October 2001 to obtain all of the necessary agreements with the store owners and begin collection of baseline data.
2. Baseline Data Collection. Water and energy use data were obtained for each store starting from January 2001 through September 2002, when the water treatment systems were installed. The stores were inventoried with respect to the water using fixtures and appliances, and basic information on their cooling systems was obtained. The operations of the cooling systems were observed under baseline conditions and programmable controllers were installed with coupon racks. Any defect such as broken bleed valves or overflow conditions were repaired and the cooling systems were monitored for a period of at least 30 days after they had achieved stable conditions. Data loggers were installed on the main water meters so that the researchers could obtain flow traces for the water use in the store and compare these to the water use recorded for the coolers by the programmable controllers.
3. Retrofits. After the systems were running in a stable condition, the controllers and coupon racks installed and the baseline water, cooler and energy data were collected, which was complete by September of 2002, the cooling systems were retrofit with their intended treatment technology. This technology was evaluated as the first priority. Stores with successful cooling treatment were then evaluated with respect to other in-store conservation opportunities.

4. Post Retrofit Data Collection and Monitoring. The cooling technologies were installed in all stores during the first week of October 2002. At this time all of the bleed rates were dropped, in order to increase the cycles of concentration to approximately 6. Each system was visited on a frequent basis after this step was taken, the water in coolers was tested, and the tube bundles were inspected. Any problems with the systems were reported to the manufacturers or their representatives, and they were given an opportunity to correct them. Systems that failed to perform were removed, and those that succeeded were left in operation. One store was switched from an unsuccessful to a successful system in order to increase the amount of data collected on the latter. Water, chemical, and energy data were collected through the end of May, 2003 so that savings could be measured and the systems' performance monitored.
5. Report. The results of the study through the end of May are included in this report.

BASELINE WATER QUALITY

To a great extent the quality of the inflow water will limit the cycles of concentration of the cooling system. The higher the levels of hardness and alkalinity in the inflow water, the greater the potential for scale accumulation at higher cycles. In this study the researchers began sampling the inflow water to the systems in September of 2002. Tests were conducted periodically at each store from September 2002 until May of 2003. Each sample was tested for the important chemical parameters for scaling: conductivity, calcium hardness, pH, alkalinity, chlorides, temperature and saturation index. The results of these tests were plotted on a series of graphs in which the tests for the inflow water for each store are grouped together and arranged chronologically from September through May. This allows one to quickly compare the relative strengths of the water for each store to each other and to themselves over the time period of the study. All of the water in these sites tended to be moderately hard and have moderate levels of alkalinity. They were all fairly similar in their chemical compositions.

Alkalinity

The alkalinity data for the feed water in each of the six stores is shown in Figure 2. This shows that over the time period of the data collection the alkalinity levels at the six stores ranged from 80 to 250 mg/l (as $CaCO_3$). During this period most of the data were between 100 and 200 mg/l, and the store with the lowest alkalinity levels were at the Sun City and Beverly stores, while the higher alkalinity levels were found at Arcadia, Irving, Santa Monica and USC. The alkalinity levels tended to rise during the winter and drop in the spring.

Hardness

Figure 3 shows the calcium hardness readings for the inflow water for the stores over the same September to May time period. Generally, the calcium levels tend to parallel the alkalinity readings with some exceptions, and they range from 50 mg/l to 250 mg/l as $CaCO_3$. In all cases the calcium hardness levels are equal to or less than the alkalinity levels. The stores with the lowest calcium readings are Beverly, Irvine, and Sun City. The fact that the alkalinity levels always exceed the calcium levels is significant because it means that the hardness in these systems is carbonate hardness, which can most easily precipitate out with high temperatures or pH levels, as will be discussed in more detail below.

Chlorides

Chloride levels in the water are important as a good indicator of concentration ratios. Chloride is a stable anion in the water and does not react or precipitate out with the cations present such as calcium or magnesium. Since it is easy to test its ratio in the circulation water to the feed water, it provides a good measure of the cycles of concentration in the system.

Figure 4 shows the data for the chloride tests at the six stores. They range from 20 to 150 mg/l, with the lowest levels found at Arcadia and Beverly stores, and the highest at the Sun City store. It is interesting that the Sun City store, which had lower levels of alkalinity and hardness had higher levels of chlorides.

Conductivity

Conductivity is a simple, if potentially misleading, parameter for measuring the total dissolved solids in water. It is measured as the ability of a solution to conduct an electric current, and is the inverse of its resistance, hence it is measured in micro mhos (A µ mho is the opposite of an ohm, the unit of electrical resistance.) The reason the conductivity can be misleading is that when calcium carbonate is precipitating out of solution (as scale) this will result in a lower conductivity reading, providing a falsely low measure of cycles of concentration, which can mask scale formation in a cooler.

Figure 5 shows the conductivity of the city water for the stores for the September through May period. The data range from a low of 400 to a high of 850 µmhos. Arcadia, Beverly and Irvine tended to have the lower conductivity waters during this period, averaging around 500 mg/l, while the Sun City, Santa Monica, and USC stores had higher conductivity readings, averaging around 700 mg/l.

pH

The pH readings of the City water are provided in Figure 6. These show that most of the pH readings were between 7 and 8, and the lower readings were at the Arcadia and Beverly stores.

Saturation Index

The saturation index of a water, or Langlier Saturation Index (LSI) is a measure of the stability of the water with respect to scale formation. The LSI for the City water readings are shown in Figure 7. When LSI readings are positive they tend to be scale forming, and when they are negative they tend to be corrosive. Normally readings within 1.0 units from zero are considered stable. Using this standard, the water at the water at the Beverly store tended to be slightly corrosive, while the other waters had all approximately the same level of scale formation potential.

Variability in Water Chemistry

Examination of the figures showing the water chemistry of the makeup water to the cooling system shows that there is a significant amount of variability in the water entering these systems. For example, conductivity readings typically vary by 50% to 100% in the range between the low and high values. This has significance when using conductivity as the primary control parameter since the cycles on concentration in the system will change if the conductivity in the system is held constant while the conductivity of the inflow water changes. Normally, these changes occur gradually over time, so that that the problem can be avoided by checking the inflow water parameters and adjusting the set-point as necessary.

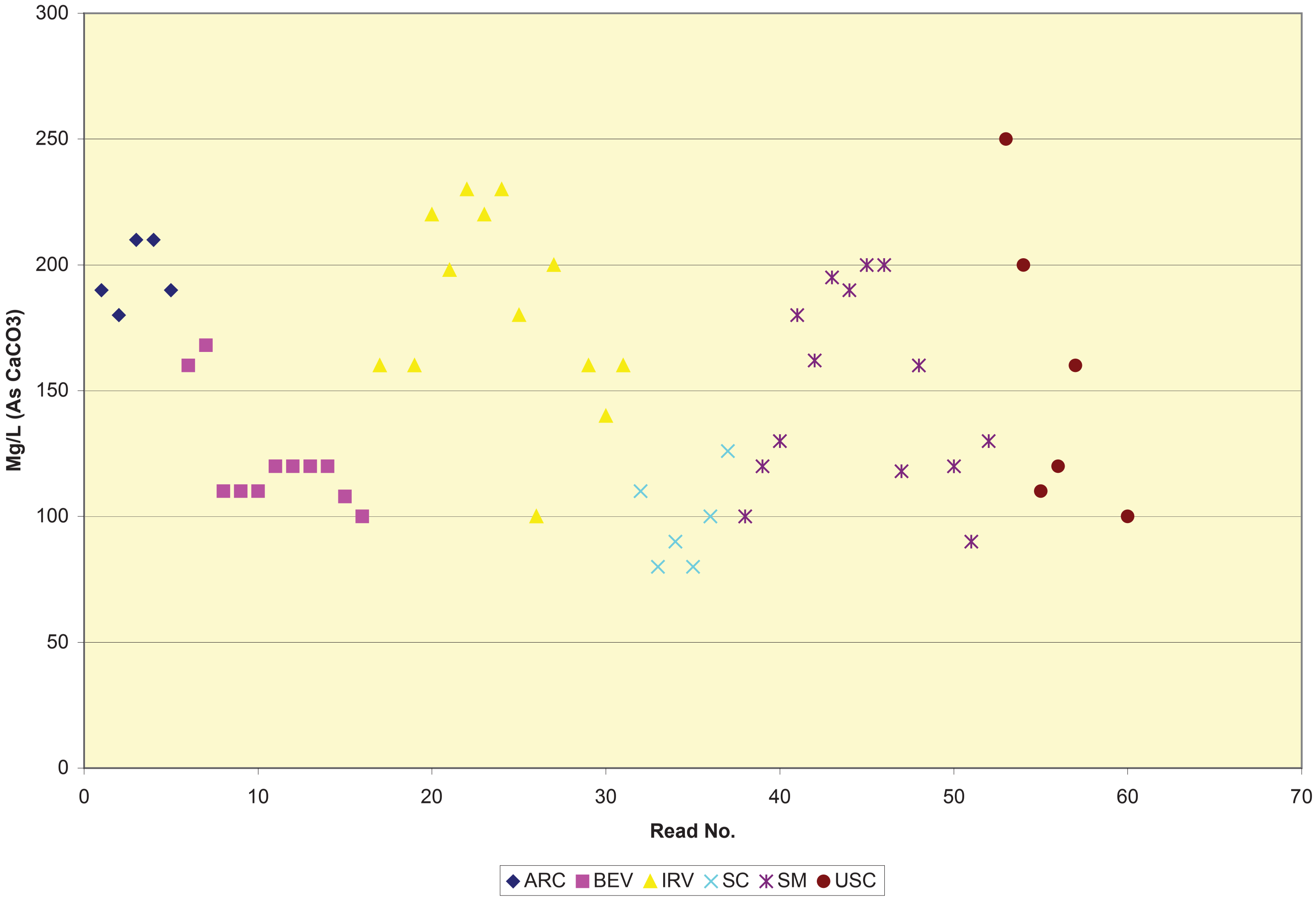


Figure 2: City Water Alkalinity

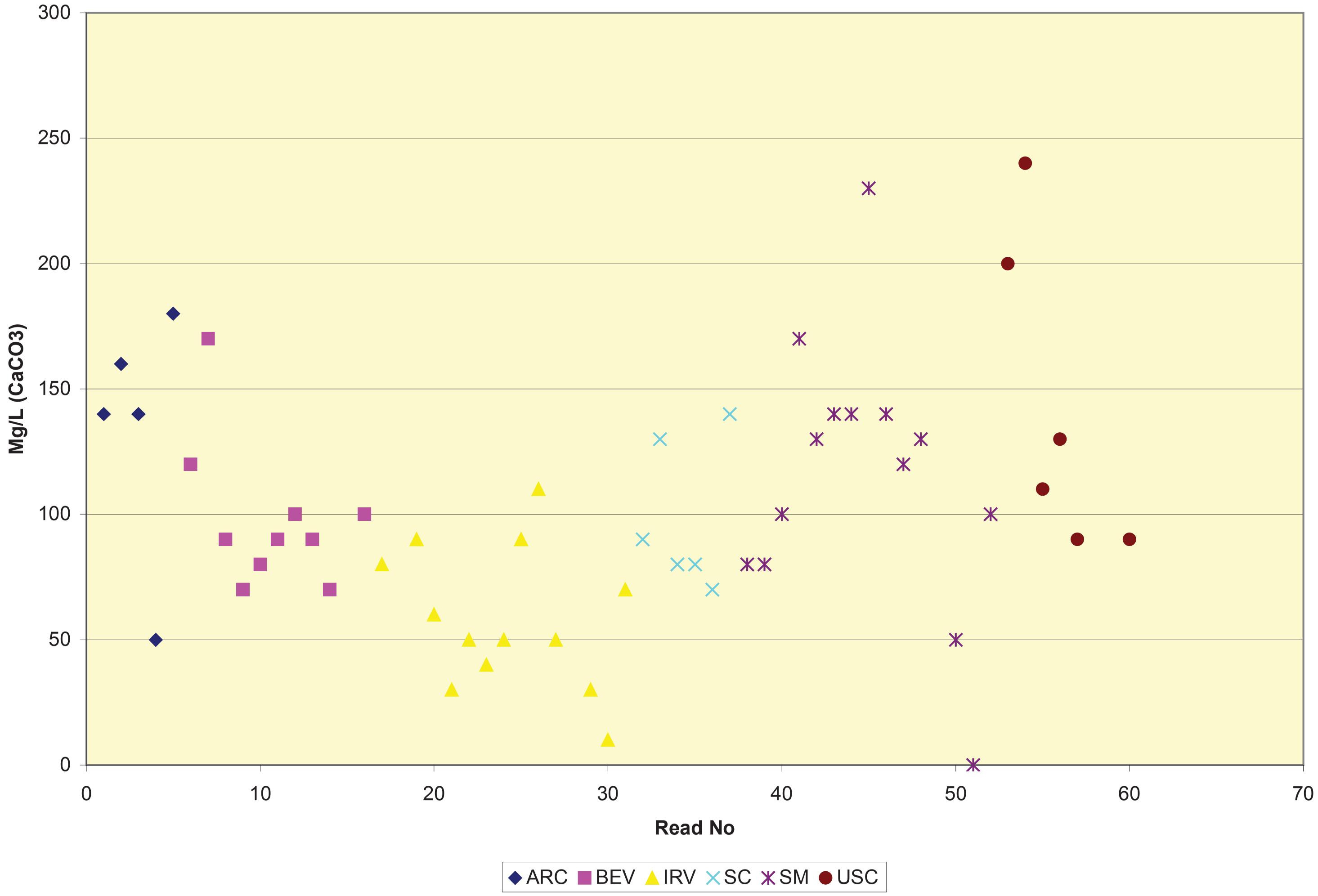


Figure 3: City Water Calcium Hardness

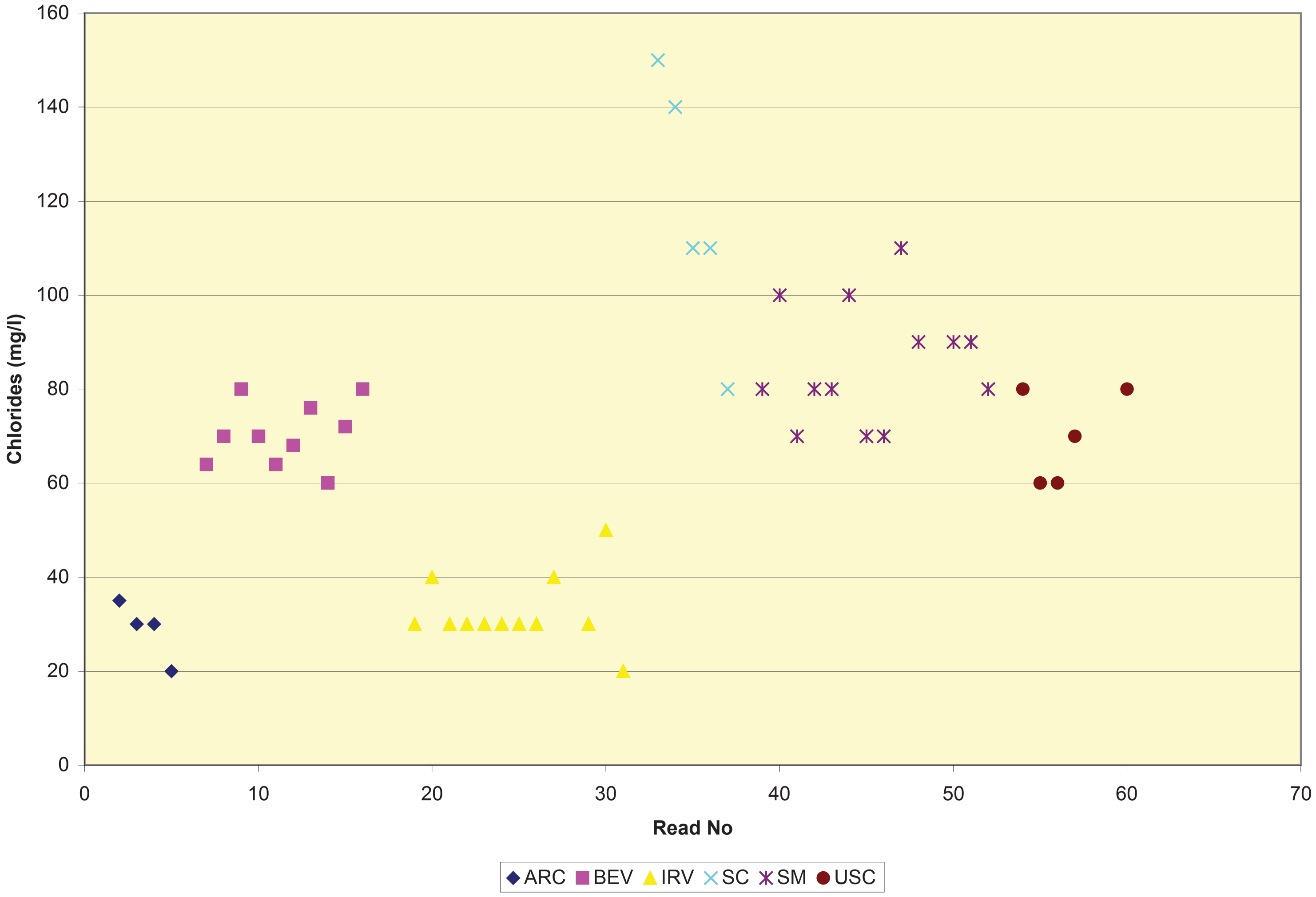


Figure 4: City Water Chloride Readings

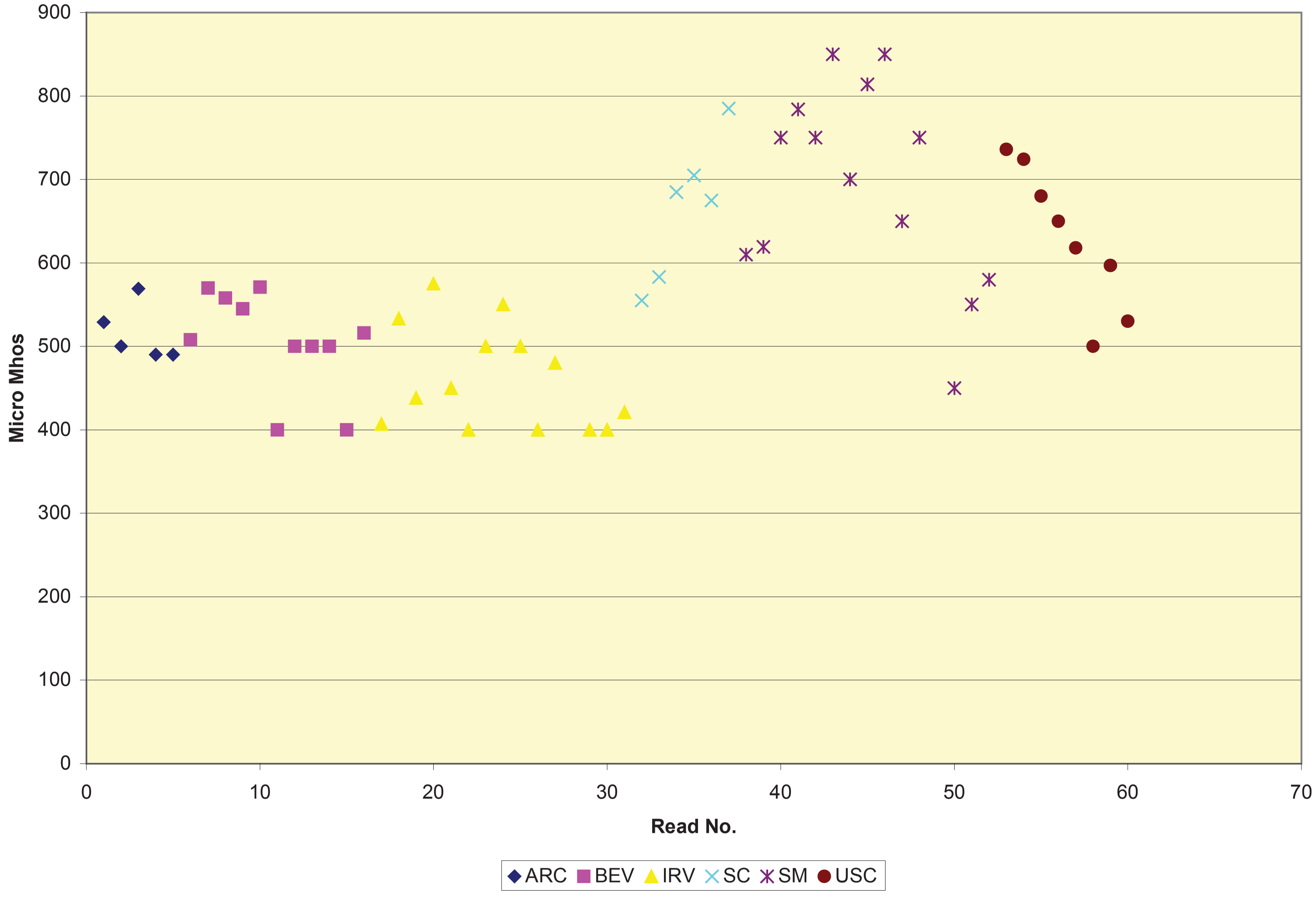


Figure 5: City Water Conductivity

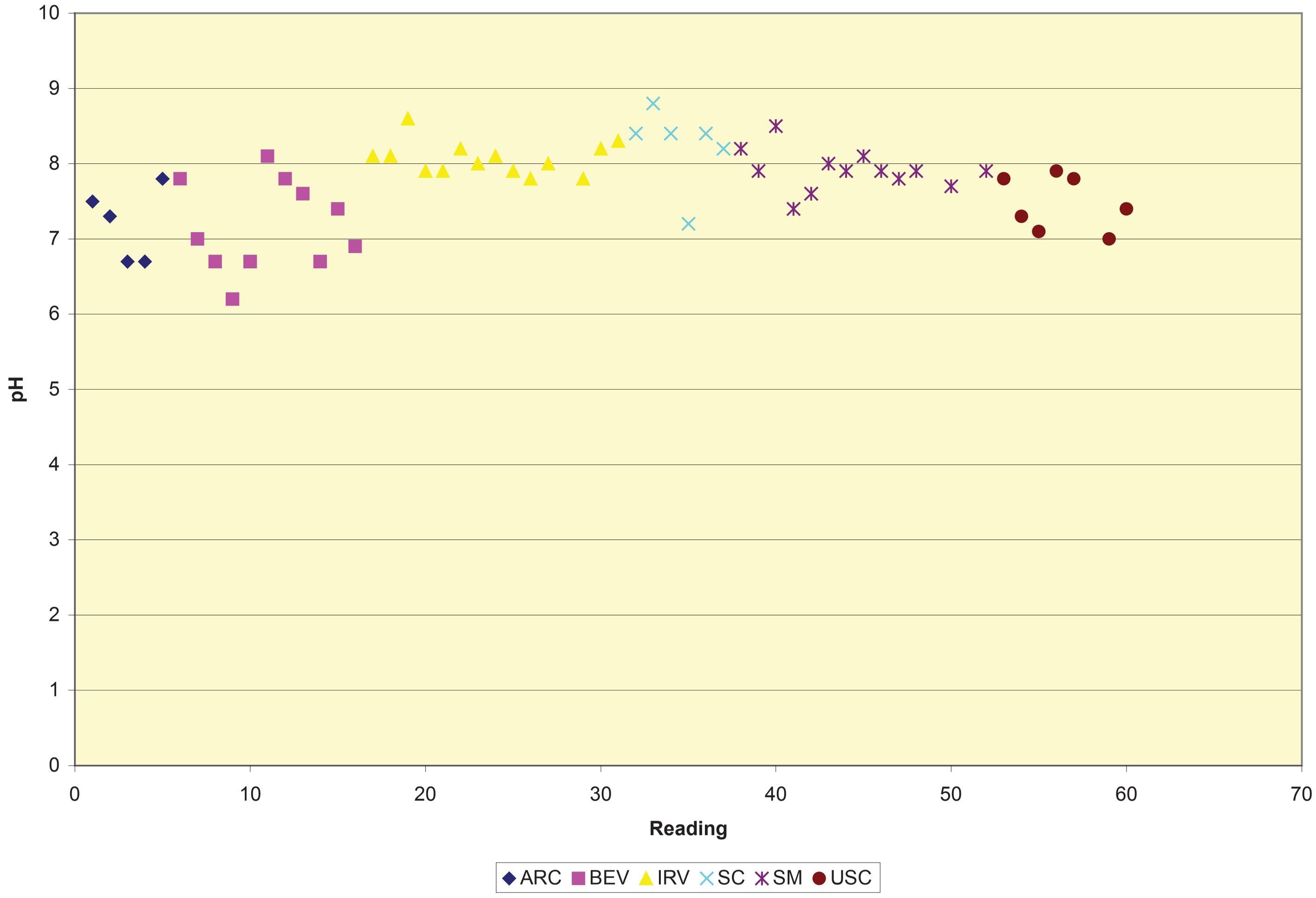


Figure 6: City Water pH

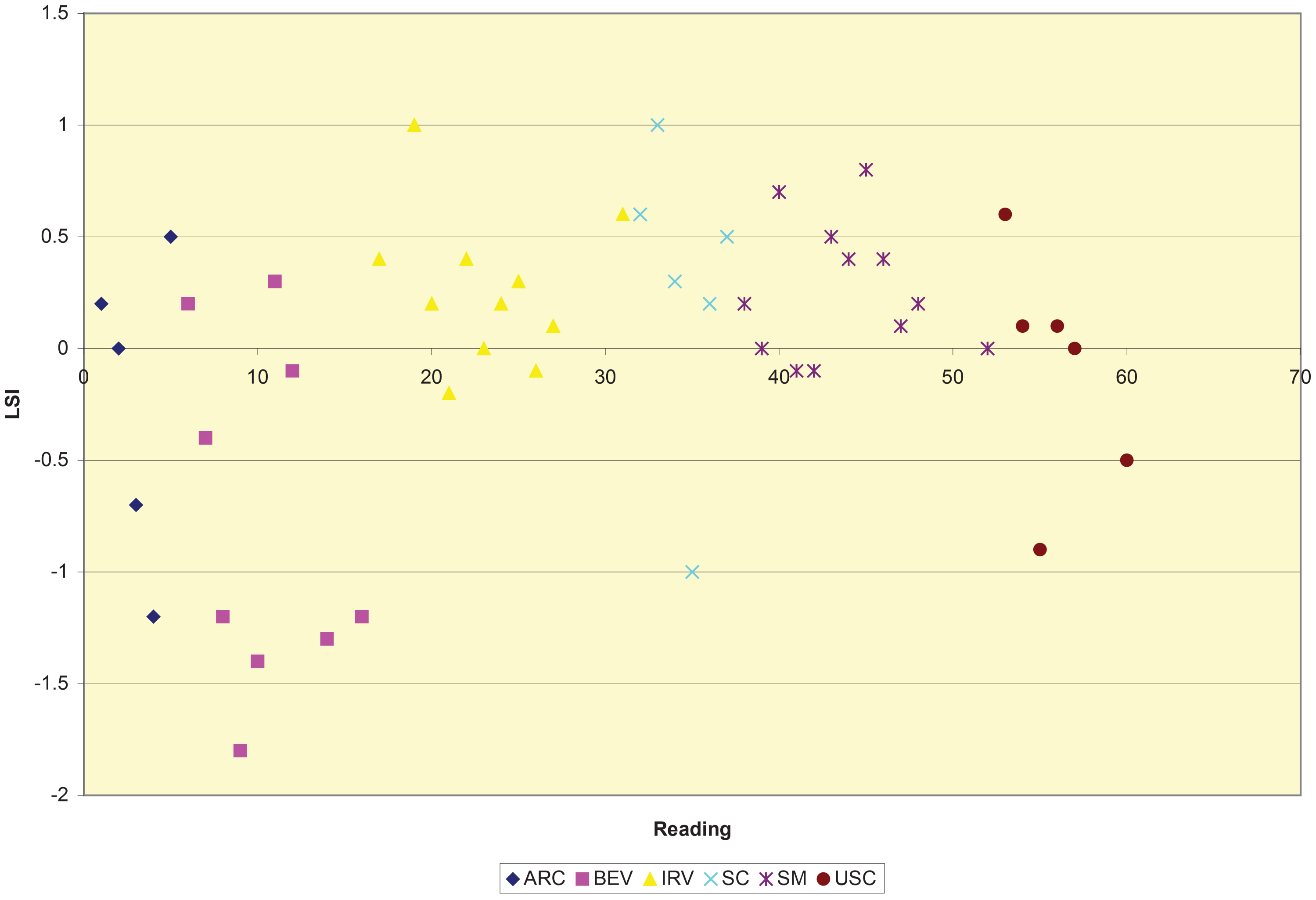


Figure 7: City Water Saturation Index

BASELINE WATER USE

This chapter presents baseline water use data for the six stores. These data were obtained from historic billing data provided by the water utilities, and more detailed data obtained from meter reads taken at each of the field visits and data logging information.

The water billing data were obtained for the calendar years of 2001 and 2002, and were either monthly or bi-monthly consumption data depending on the utility. All utilities billed in units of hundreds of cubic feet (HCF), and these units were converted to thousands of gallons for analysis (kgal). The baseline period starts in January 2001 and runs through September 2002. The water treatment equipment was installed on the coolers during the week of October 8th, which concluded the baseline period and began the active study period. All water consumption data were converted from hundreds of cubic feet (HCF) to gallons or thousands of gallons (kgal) for uniformity and ease of analysis. With the exception of one store, Santa Monica, no irrigation water was delivered through the store water meters. Not having to correct for irrigation greatly simplified the analysis. In the case of Santa Monica the daily water use for irrigation was determined for the data logging period of June 1 through July 12th, 2002.

Starting in April of 2002, personnel from Aquacraft began visiting the sites on a fairly regular basis. At each visit the main water meter for stores and the inflow and bleed meters on the evaporative condensers were read. Data loggers were installed on the main water meters sometime during the period from April through September 2002. These loggers were programmed to record the flow into the stores through the main meters on a 1-minute basis. From these data, hourly and daily summaries were prepared. Unfortunately, due to the nature of the meters and the harsh conditions of the meter pits (which were often flooded) not all of the flow trace data from the loggers were usable. However, the researchers did obtain enough data at each site combined with the data from the cooler controllers to provide a good picture of the daily and hourly water use patterns at each of the stores.

Another key source of water use data was from the programmable controllers installed on the coolers. These were all in place by the end of March 2002. In addition to providing data on the chemistry of the water in the coolers, they also provided hourly data on the inflow of water to the coolers from the city plumbing system. The combination of these data with those from the main meter loggers allowed simultaneous graphs of water use to be made of hourly and daily water use for the store as a whole, for cooling use, and for in-store uses. This provided a revealing look at the similarities and differences in water use at the six stores.

Initially, water meters were installed on cooler bleed lines so that it would be possible to have direct measurements of the inflow and bleed from the condensers. Having this information would make it unnecessary to estimate the split between evaporation and bleed, since it would be possible to measure the bleed. Unfortunately, the amount of solids and debris in the bleed line was so great that it plugged up the bleed meters and made their readings unreliable. Consequently, the researchers relied on the water chemistry readings on the inflow and bleed to estimate the cycles of concentration in the system from which the bleed rates were determined mathematically. Fortunately, the meters on the inflow lines performed well, and those measurements were accurate.

The water use data has been presented here in both graphical and tabular form, with the stores in alphabetical order. The reader is cautioned to keep in mind that the data from each source (billing, meters and data loggers) comes from different time periods. So there is some unavoidable inconsistency in the average values for each category of use. There is a considerable amount of variability in the water use in these stores, and snapshots taken from different time periods will all be slightly different. Each store, however, has an overall water use pattern that can be discerned in the data. Significant changes in these patterns due to water conservation efforts should be quantifiable, provided they are great enough to create statistically valid change in the average use patterns.

Arcadia

Annual and Monthly Water Use from Billing Records

During the 20-month period from Jan. 2001 to August 2002, the Arcadia store used a total of 3,735 kgal of water (3.7 million gallons). Water meter reads were bi-monthly, so the monthly consumption was estimated as half of the bi-monthly use.

Water use did appear to vary seasonally during 2001. Use gradually increased from January to August and then declined in September. This pattern is what one would expect due to increased cooling loads during the warmer months of the year. The use in November-December, however broke the pattern and was larger than any but the May-June period. Overall, there was a trend of increased usage over the year. It is not clear whether this was trend was due to an increase in activity in the store during this period or was due to unusually low use during the beginning of the year. Using just data from the billing record it is more difficult to explain the observation because it is not known how much of the water was used for cooling or in-store use in any period. Data obtained during the field study provided a more complete picture of water use.

Water use exhibited less of a seasonal pattern from January to September 2002. Water use stayed mainly between 150 and 200 kgal per month.

Table 12: Bimonthly baseline water use data for Arcadia

Month	Use (kgal)	Percent of Total
Jan/Feb-01	195	5%
Mar/Apr-01	289	8%
May/Jun-01	570	15%
Jul/Aug-01	434	12%
Sep/Oct-01	340	9%
Nov/Dec-01	507	14%
Jan/Feb-02	412	11%
Mar/Apr-02	306	8%
May/Jun-02	298	8%
Jul/Aug-02	384	10%
Total	3735	
Ave Bimonthly	374	
Ave Day	6.2	

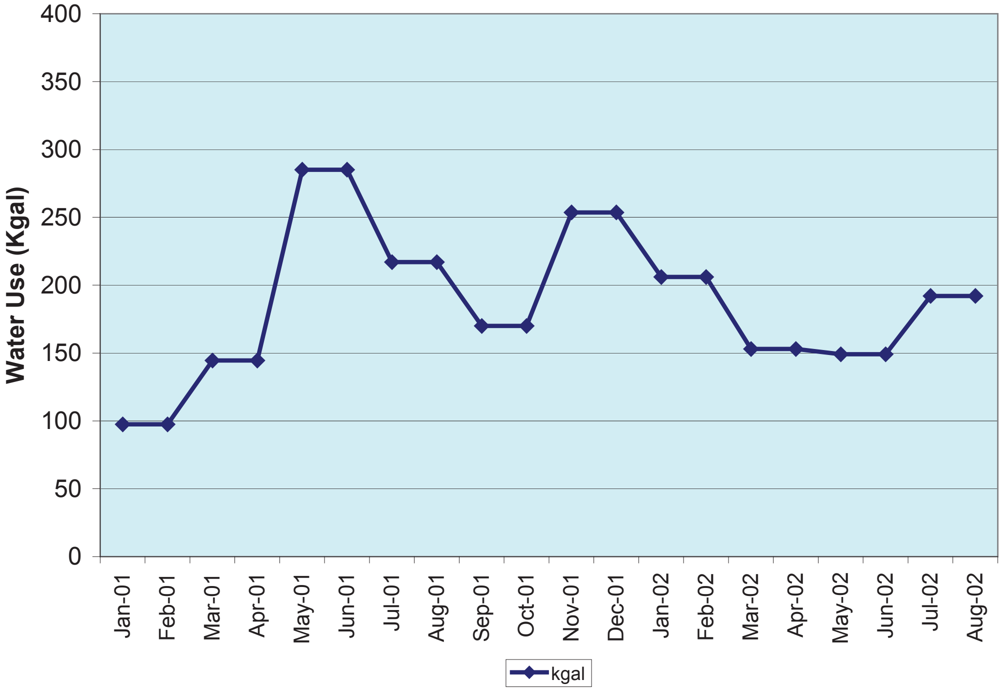


Figure 8: Monthly water use in Arcadia, Jan. 2001- Aug. 2002

Daily Use During Logging Period

Beginning in April 2002, separate meter readings were available on from the main meters, the inflow to the cooling towers and on the bleed lines. This allowed the water use to be broken down into cooling, in-store, evaporation and bleed. Figure 9 shows that during the period from April 27th to October 8th, prior to modification of the cooling treatment process, the average daily use in the store was 4,924 gpd, which is reasonably close to the average daily use during 2001. Of this, 3,610 gpd were used by the evaporative condenser. This is equivalent to 73% of the total water use at the store devoted to cooling, while only 1,313 gpd, or 27%, goes for all other uses in the store.

Of the water used for cooling, 2,638 gpd evaporates from the system and 973 gpd was bled from the system. This implies that during this period the cooling system was being run at an average concentration ratio of 3.7. [1]

The daily use data for the main meter and the cooling make-up water are shown in Figure 10. The total daily water use (blue triangles) is just above the cooling water use (pink squares) for this period, and the ratio between total use and cooling use remains very constant, except for a brief period for which cooling data were not available in July. Water use can be seen to gradually increase through the end of July and then decreases in August. Clearly, at this store, the main water use is for cooling and changes in water use are driven by changes in cooling demands.

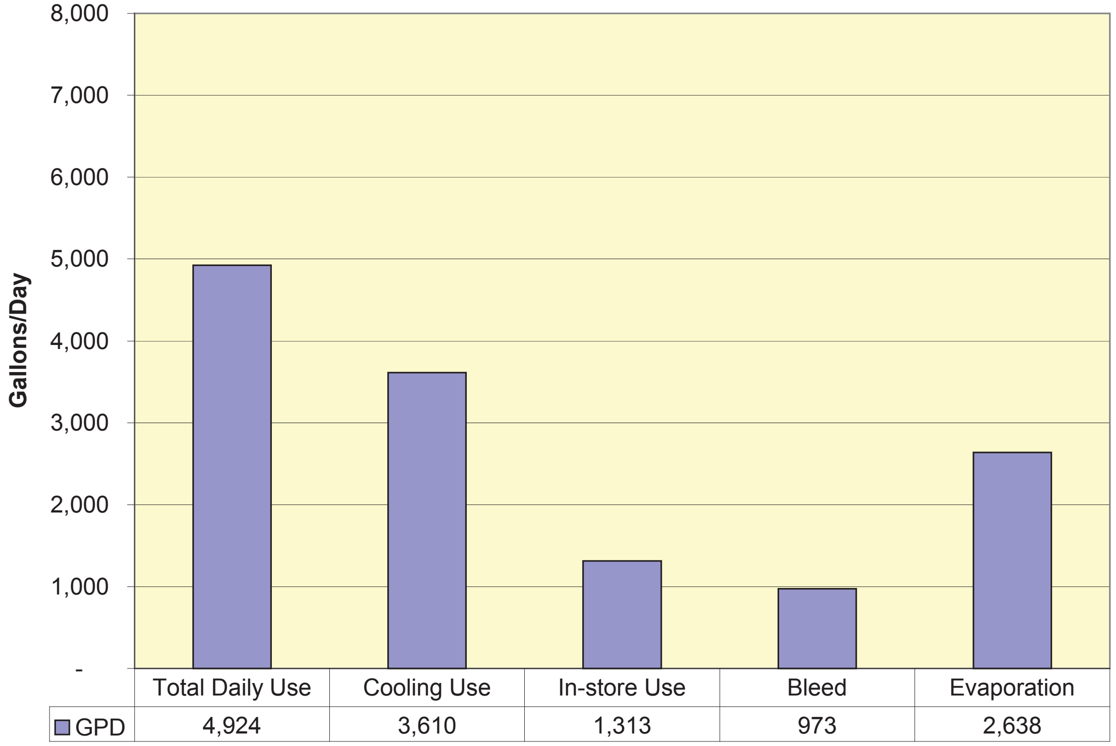


Figure 9: Average daily baseline water use at Arcadia (4/28/02 – 10/8/02)

---

[1] This bleed value may be incorrect because the meter may have plugged with sediment during the period. A low bleed value would give an erroneously high estimate of concentration ratio. Data during the test period suggest this to be the case.

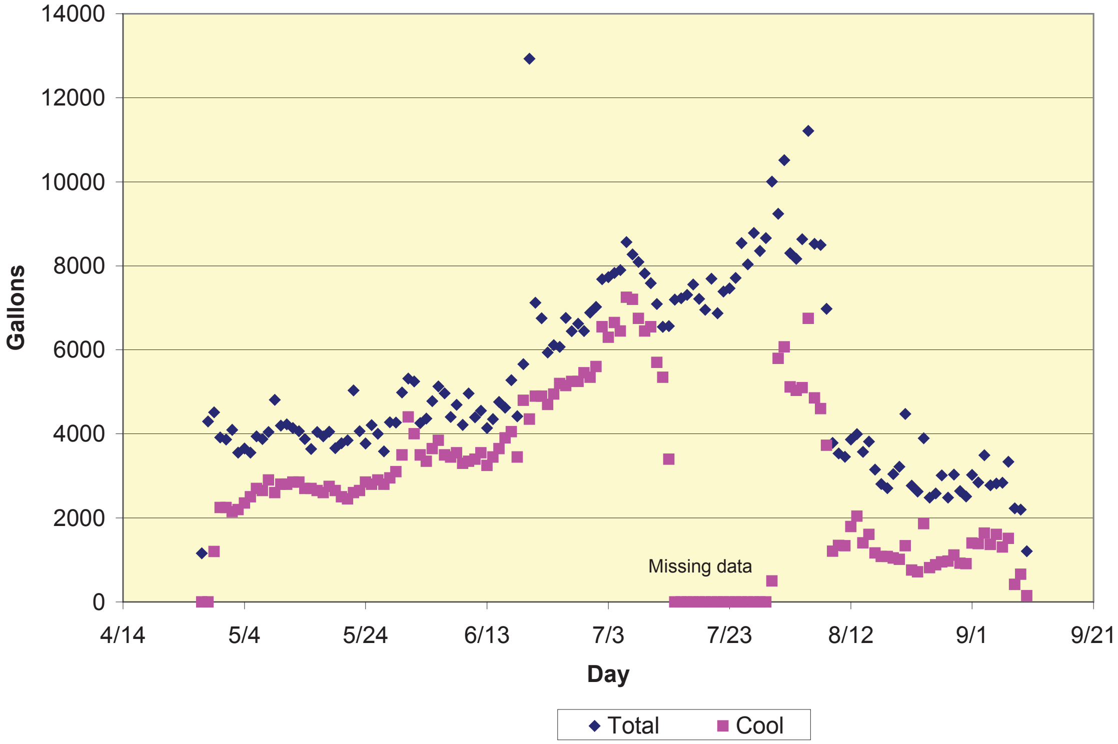


Figure 10: Daily use data—Arcadia

Hourly Use

Data from the period covering June 2 to July 13th was summarized on an hourly basis, shown in Figure 11. This graph represents the average hourly flow for each day during the June 2nd to July 13th period. The cooling use during this period was very constant during the day, and hovered around 200 gallons per hour. There was a slight increase in in-store water use in the evening, between 7:00 and 9:00 PM. This is probably for clean-up. The overnight low flows drop to around 20 gallons per hour, which could be leakage. It is interesting to note that in-store use never comes close to the cooling use, except for a brief period in the early evening, but then it just reaches slightly over half of the cooling use.

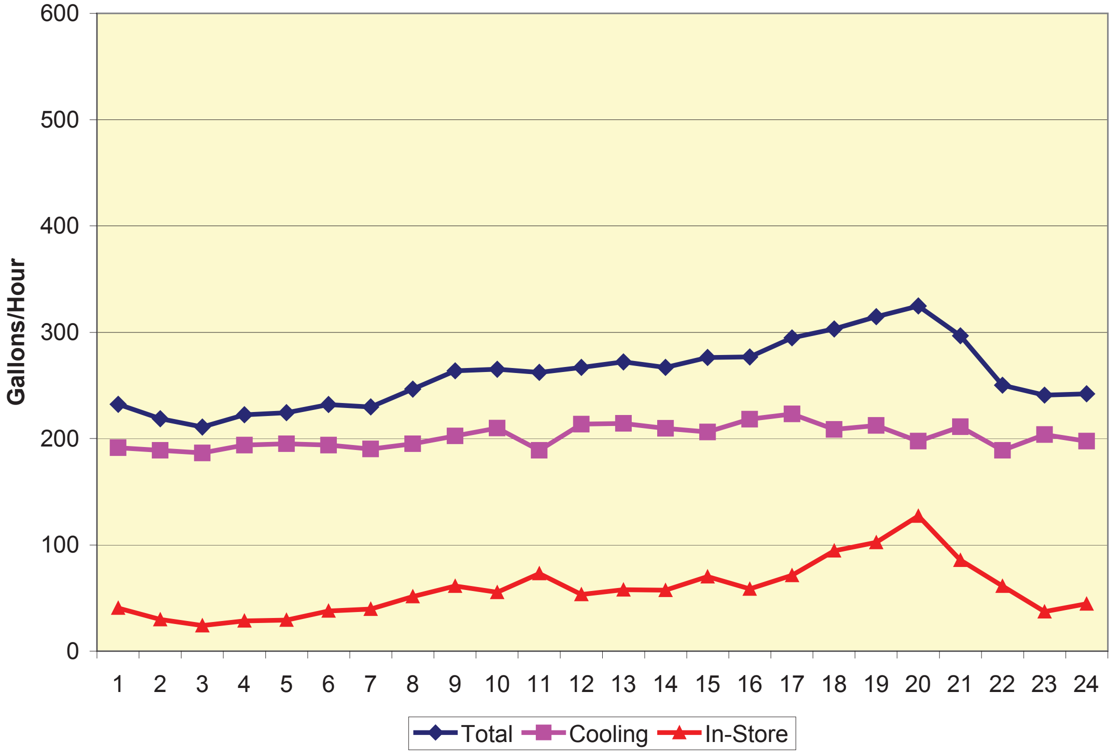


Figure 11: Hourly use data--Arcadia

Beverly

Annual and Monthly Use

During the 21 month period from Jan 2001 to September 2002, the Beverly store used a total of 8,871 kgal of water (8.9 million gallons). As shown in Table 13 and Figure 12 there was a very distinct decrease to the monthly use over the period. During 2001 there were 7 months when consumption was over 500 kgal, but starting in January 2002 use settled down to around 300 kgal per month and remained at that level through September. It is not clear why this decrease occurred.

Table 13: Monthly water use at Beverly

Month	Use (kgal)	Percent Of Total
Jan-01	740	8%
Feb-01	345	4%
Mar-01	531	6%
Apr-01	580	7%
May-01	444	5%
Jun-01	595	7%
Jul-01	613	7%
Aug-01	568	6%
Sep-01	454	5%
Oct-01	522	6%
Nov-01	466	5%
Dec-01	400	5%
Jan-02	304	3%
Feb-02	314	4%
Mar-02	292	3%
Apr-02	307	3%
May-02	272	3%
Jun-02	268	3%
Jul-02	251	3%
Aug-02	373	4%
Sep-02	232	3%
Total	8871	
Ave Month	422	
Ave Day	13.85	

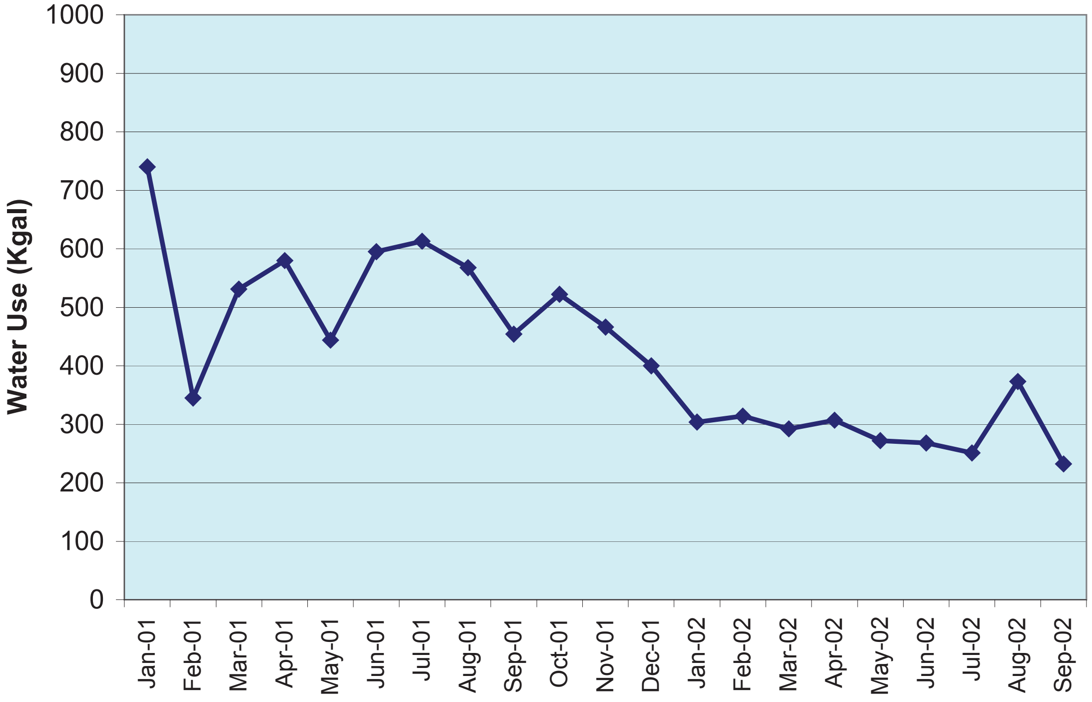
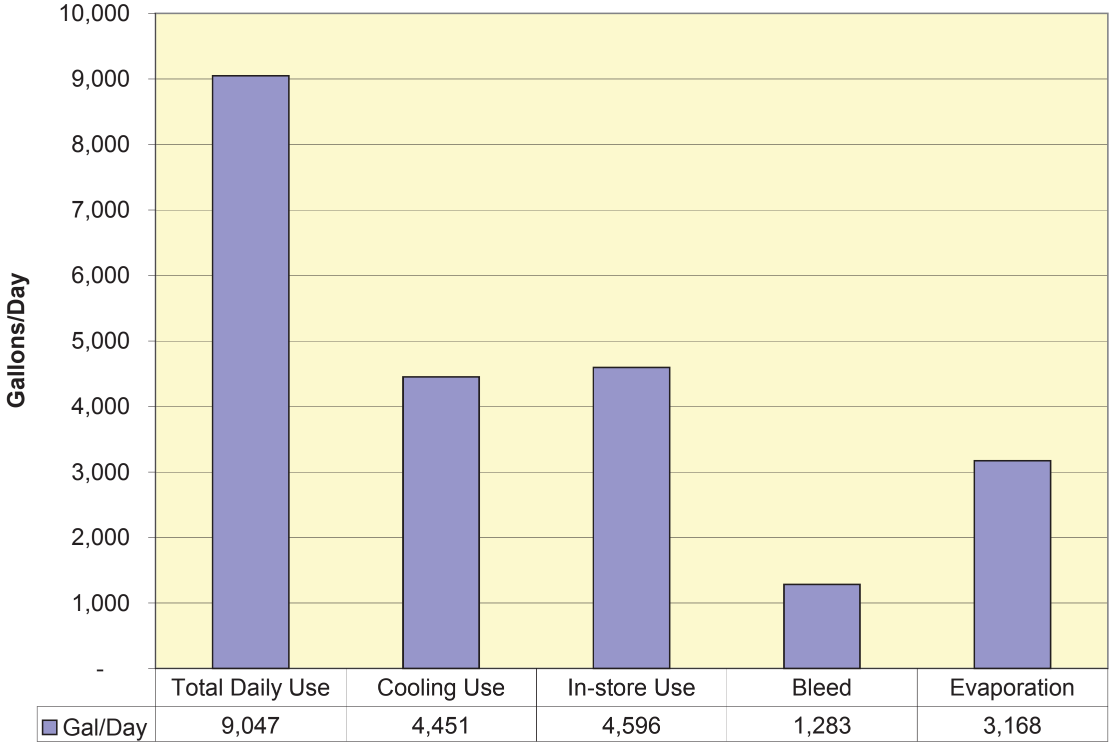


Figure 12: Monthly water use at Beverly

Daily Use During Baseline Period

The average daily use is broken down in Figure 13 for the baseline period. This shows that during the April through July period the average daily use for the store as a whole was 9,047 gpd. Out of this, 4,452 gpd (49%) were used for make up to the cooling tower. Of the make up, 1,283 gpd were measured by the bleed meter leaving 3,168 gpd was for evaporation. Based on the ratio of the bleed water to the make up water, the average cycles of concentration of the cooling water was around 3.5 during this period. The data show that over half of the total water use is for in-store purposes at the Beverly store, amounting to nearly 5,000 gpd of use for all non-cooling related purposes.



	Total Daily Use	Cooling Use	In-store Use	Bleed	Evaporation
▨ Gal/Day	9,047	4,451	4,596	1,283	3,168

Figure 13: Average daily baseline use at Beverly

A look at the daily use data obtained from the flow recorders on the main and cooling feed meters shows that the total use in the stores is closely linked to the cooling use. Figure 14 shows that at the start of the logging period the total daily use was at the store was around 10 kgal and the cooling use was around 6 kgal. Between the 1st and the 18th the cooling use dropped by 2.5 kgal per day (from 6 to 3.5 kgal). During the same period the total water use dropped by almost the same amount, 3.5 kgal as it dropped from 10kgal to 6.5 kgal. This close linkage between changes in cooling use and changes in total store use strongly suggests that the in-store use tends to be fairly regular, and that changes in cooling use will be reflected in total store use, even over a short period of time.

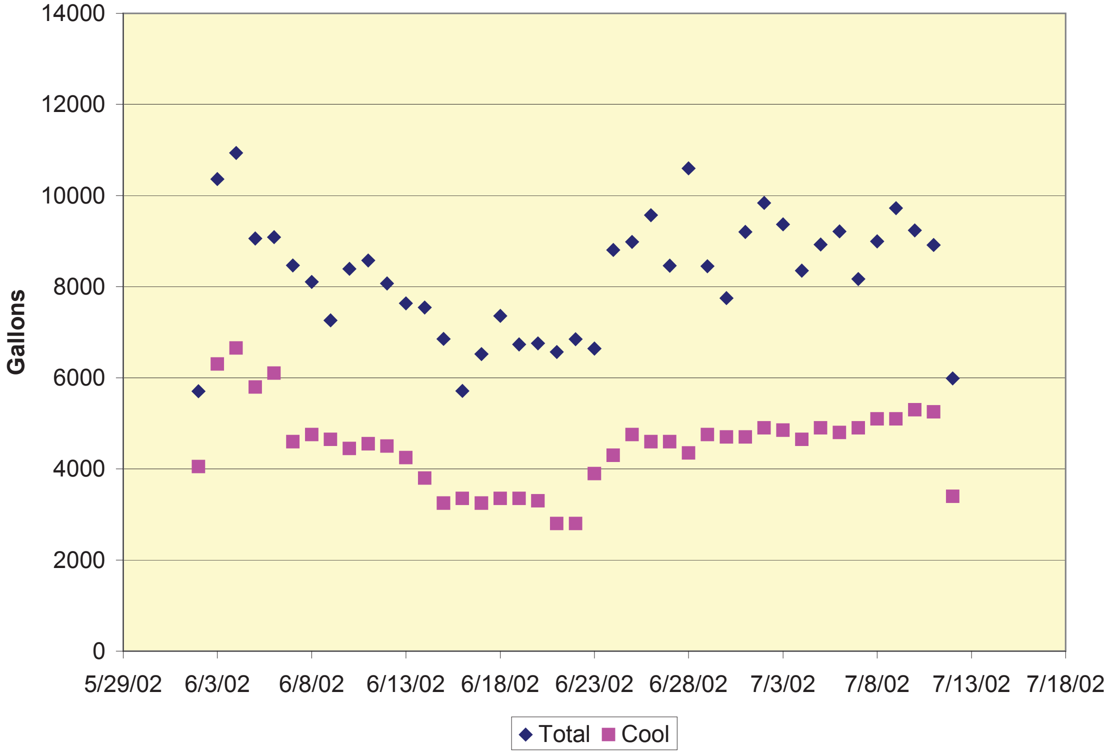


Figure 14: Daily use at Beverly store

Hourly Water Use at Beverly

When the data from the loggers was summarized on an hourly basis it was possible to average the water use for each hour of the day and show how the in-store and cooling water use in the store varies over a typical 24 hour period. This information is shown in Figure 15. During the five week period for which logging data were available it can be seen that the cooling water use stayed very close to 200 gallons per hour (3.33 gpm) over the day. The in-store use began ramping up at 5:00 am, reached its peak around noon, and then stayed at around 220 gph until 8:00 PM, when it gradually decreased until midnight. The peak between midnight and 2:00 is due to a combination of produce preparation and cleaning.

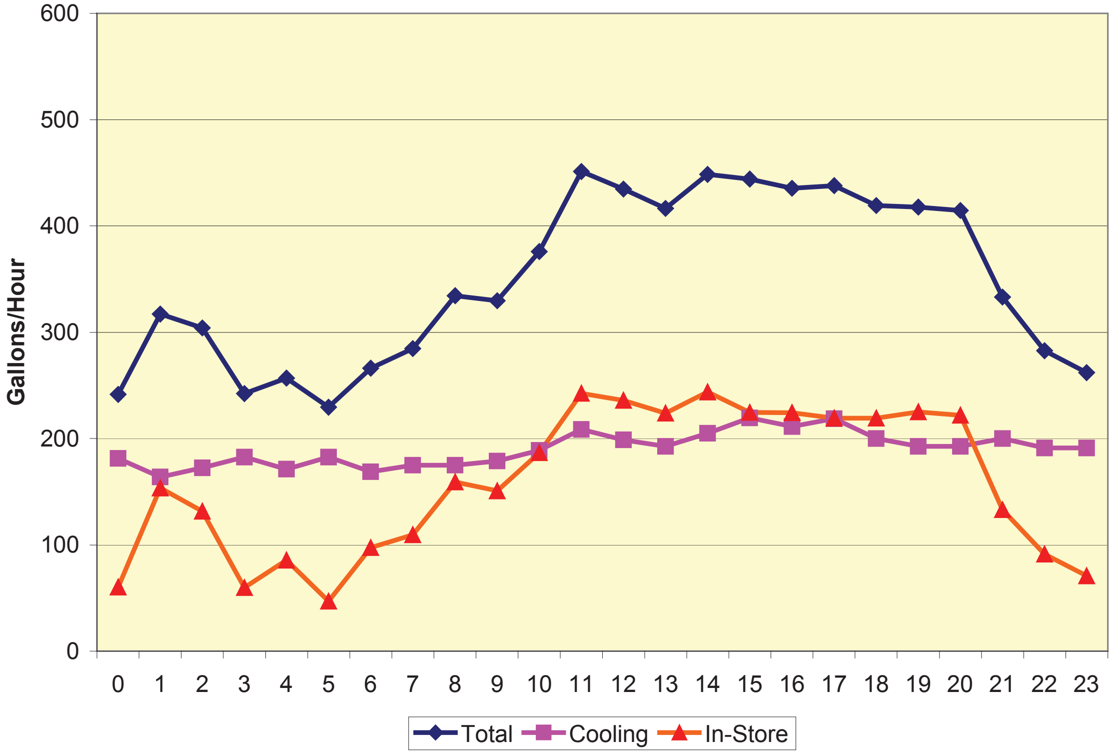


Figure 15: Hourly Water Use at Beverly

Irvine

Annual and Monthly Baseline Use

During the 21 month period from Jan 2001 to September 2002, the Irvine store used a total of 7,086 kgal of water (7.1 million gallons). As shown in Table 14 and Figure 16, water use was just below 300 kgal from January to April of 2001 and most of 2002. Water use was slightly higher between May 2001 and January 2002, peaking at 430 kgal.

Table 14: Monthly water use at Irvine

Month	Use (kgal)	Percent of Total
Jan-01	281	4%
Feb-01	278	4%
Mar-01	276	4%
Apr-01	285	4%
May-01	318	4%
Jun-01	352	5%
Jul-01	394	6%
Aug-01	357	5%
Sep-01	434	6%
Oct-01	428	6%
Nov-01	334	5%
Dec-01	412	6%
Jan-02	420	6%
Feb-02	328	5%
Mar-02	285	4%
Apr-02	281	4%
May-02	288	4%
Jun-02	335	5%
Jul-02	314	4%
Aug-02	341	5%
Sep-02	344	5%
Total	7086	
Ave Month	337	
Ave Day	11.25	

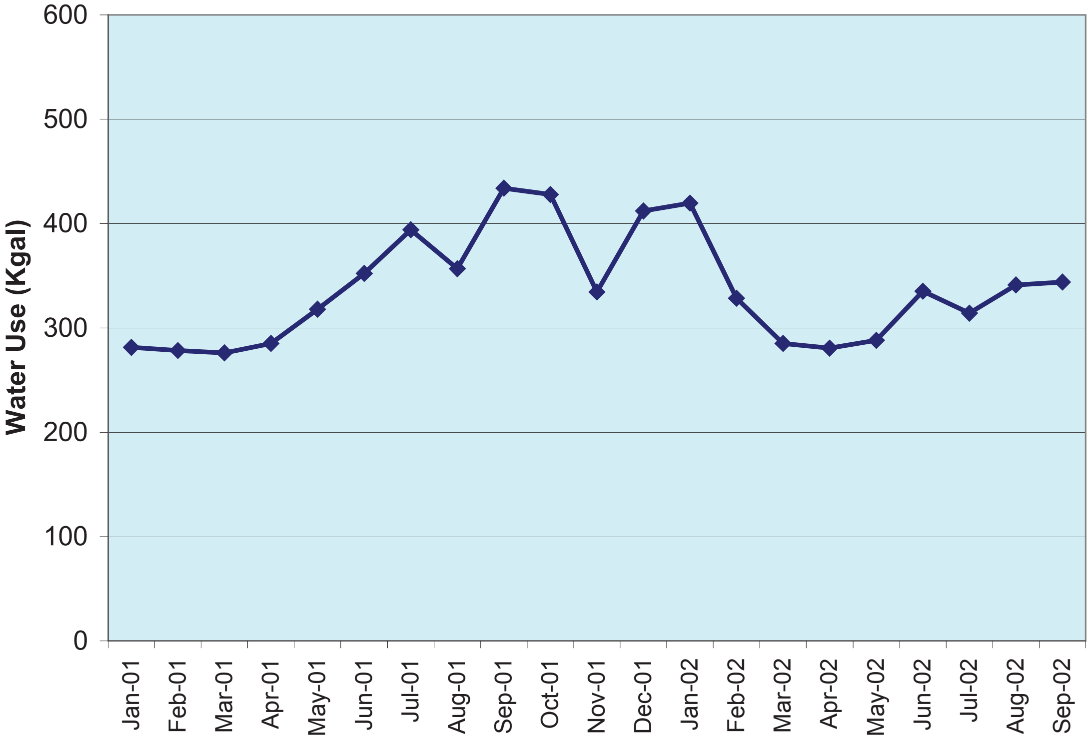


Figure 16: Monthly water use at Irvine.

Daily Use During Baseline Period

The average daily use is broken down in Figure 17 for the baseline period. This shows that during the April through October period the average daily use for the store as a whole was 10,734 gpd. Out of this, 3,867 gpd (36%) were used for make up to the cooling tower. Of the make up, 1,547 gpd were measured by the bleed meter leaving 2,320 gpd was for evaporation. Based on the ratio of the bleed water to the make up water, the average cycles of concentration of the cooling water was around 2.5 during this period. The data show that over half of the total water use is for in-store purposes at the Beverly store, amounting to nearly 6,900 gpd of use for all non-cooling related purposes.

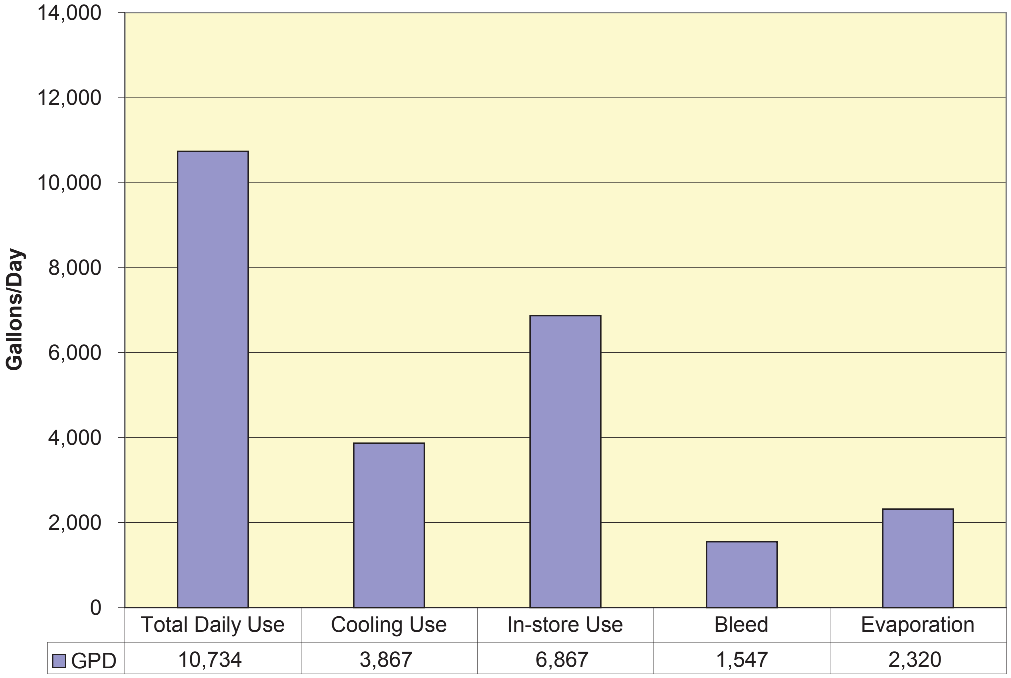


Figure 17: Average daily baseline use at Irvine (4/28/02 – 10/10/02).

A look at Figure 18 shows that the cooling use remained quite constant while the total store use varied just slightly. For the majority of the logged period, the cooling use remained just above 4 kgal. The majority of the values for the total store use were between 11 and 13 kgal, although there were a few outliers. Nevertheless, the ratio between total cooling use and total store use stayed quite constant. This suggests that changes in total cooling use will likely be reflected in total store use.

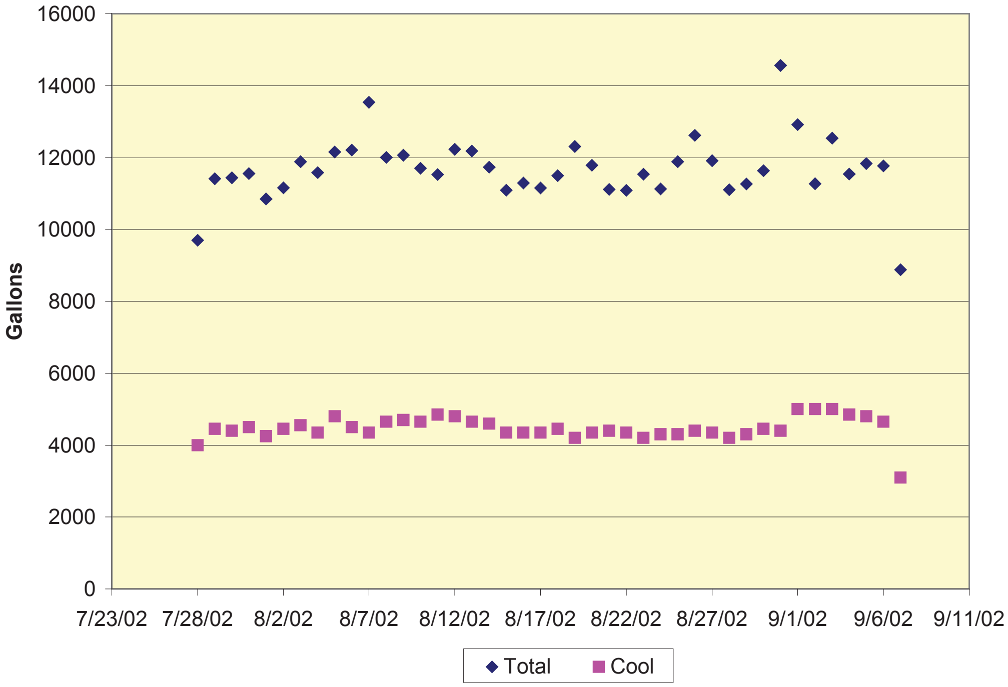


Figure 18: Daily use at Irvine store

Hourly Use at Irvine

When the data from the loggers was summarized on an hourly basis it was possible to average the water use for each hour of the day and show how the in-store and cooling water use in the store varies over a typical 24 hour period. This information is shown in Figure 19. During the period for which logging data were available it can be seen that the cooling water use stayed very close to 200 gallons per hour (3.33 gpm) over the day. The in-store use began ramping up at 7:00 am. Between noon and 3:00 there was a large block of water used for cleaning the meat department. This activity was observed and the personnel were interviewed about the practice. They use standard hoses with garden-type nozzles to wash all of the implements, counters, cutting racks and floors on a daily basis. This washing uses approximately 800 gallons of water per day. The reason for the peak between 8:00pm and 10:00pm is unknown, be may be due to a combination of produce preparation and cleaning.

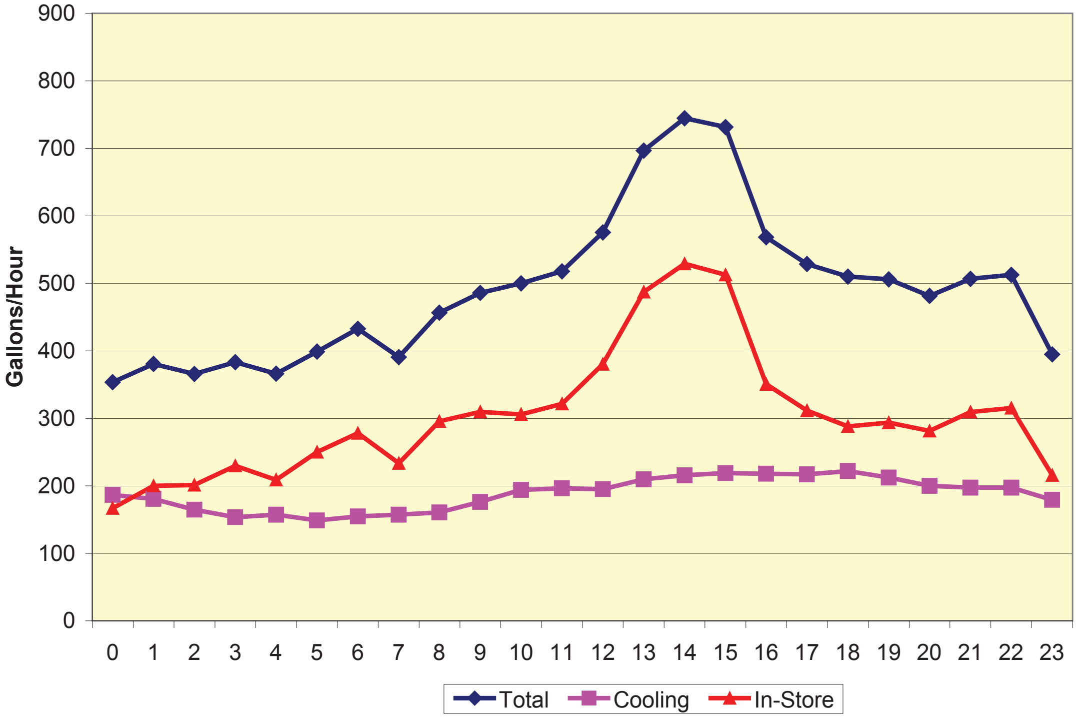


Figure 19: Hourly Water Use at Irvine

Santa Monica

Annual and Monthly Baseline Use

Water Meter reads were bi-monthly, so the monthly consumption was estimated as half of the bi-monthly use. The Santa Monica store was the only site where irrigation water was delivered through the same meter that supplied the store. During the period that data loggers were in place, it was possible to net out the irrigation water use, but for the other months it was necessary to extrapolate. The presence of the irrigation and other landscape uses on this meter added an element of uncertainty to the water use data, and made the data logger and cooling system data more important.

During the 21 month baseline period this store consumed an average of 376 kgal per month and its total consumption for the period amounted to 7,892 kgal (7.89 million gallons). The average daily use was 12.3 kgal. The researchers know from the logging that during the April-September period of 2002 there were approximately 2,000 gallons per day used for irrigation and landscape uses, but during this period the water use was lower than it was in January and February. This implies that the outdoor use was not seasonal, but was fairly constant over 2002.

Figure 20 shows that the water use from March through September 2002 was consistently around 350 kgal per month. This graph shows that the water use during the period was highly variable, with large amounts of use recorded during both the summer of 2001 and the winter of 2002. This is probably is more related to the irrigation and landscape use than the supermarket. In March of 2002 to the end of the year the water use leveled out, which is helpful for getting an estimate of the stores baseline use.

Table 15: Monthly Water Use at Santa Monica

Month	Use (kgal)*	Percent of Total
Jan-01	396	5%
Feb-01	396	5%
Mar-01	409	5%
Apr-01	409	5%
May-01	315	4%
Jun-01	315	4%
Jul-01	459	6%
Aug-01	459	6%
Sep-01	295	4%
Oct-01	295	4%
Nov-01	389	5%
Dec-01	389	5%
Jan-02	457	6%
Feb-02	457	6%
Mar-02	332	4%
Apr-02	332	4%
May-02	355	4%
Jun-02	355	4%
Jul-02	351	4%
Aug-02	351	4%
Sep-02	379	5%
Total	7892	
Ave Month	376	
Ave Day	12.53	

* Includes irrigation

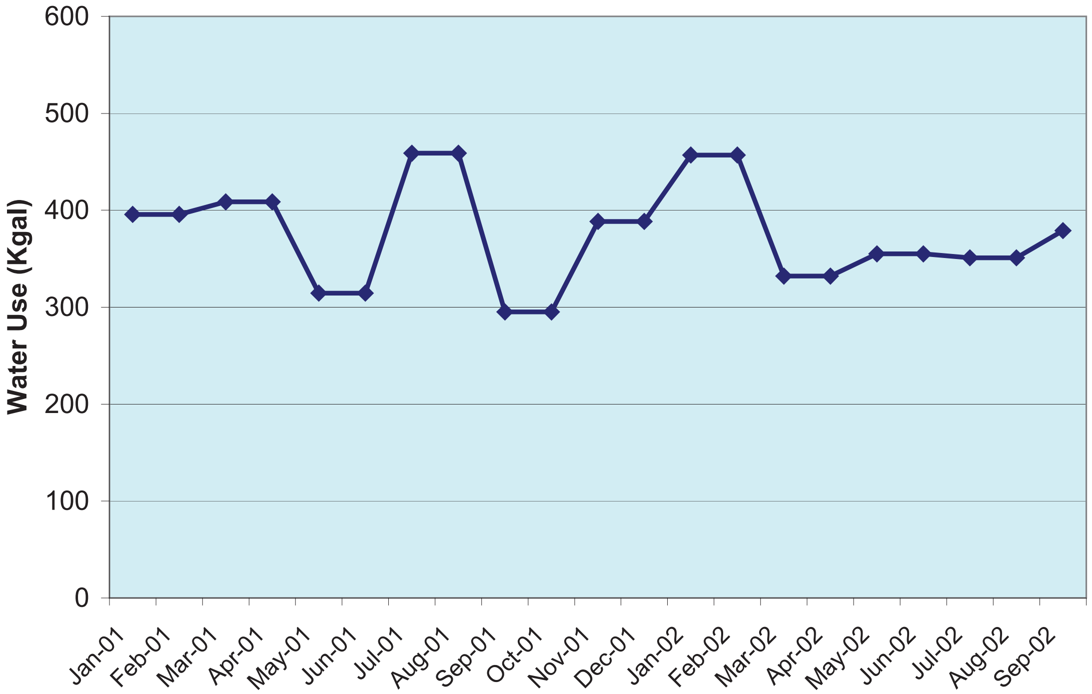


Figure 20: Baseline water use at Santa Monica

Daily Use During Baseline Period

Starting in April of 2002, this store was visited by the project engineers and readings were taken from the main meter and the meter on the cooler feed line. In addition, water use data were obtained from data loggers on the main meter and the Chemtrol® controller on the evaporative condenser. These data allowed much more precise estimates to be made of in-store and cooling water use during the period that could be obtained from just the main meter readings. The water meter installed on the bleed line from the evaporative condenser became so fouled with dirt and scale that it became unreliable for obtaining a direct measurement of bleed rates from the system.

Good flow trace data from both the main meter and the evaporative condenser controller were collected for the period from June 1 through July 12th at this store. In addition, meter readings were taken from the main meters and the meters on the evaporative condenser during site visits starting in April 2002. This allowed accurate estimates to be made of average daily water use during the April through September period. (It was necessary to assume that the irrigation rate observed during the logging period was relatively constant during the entire period.)

Figure 21 shows the average daily water use for cooling, irrigation, in-store, bleed and evaporation for the period from April 27 through October 10th as determined from combining the water meter and data logger information. During this period the amount of water used for cooling make-up was the greatest single end-use of water, which was followed by in-store uses and irrigation. Approximately 56% of the make-up water was devoted to bleed and 44% went to evaporation. This means that the cooling system was being operated at an average cycles of concentration of on 1.79 over the period, which is a very low level and implies a good potential for water savings from improvements to the cooling system.

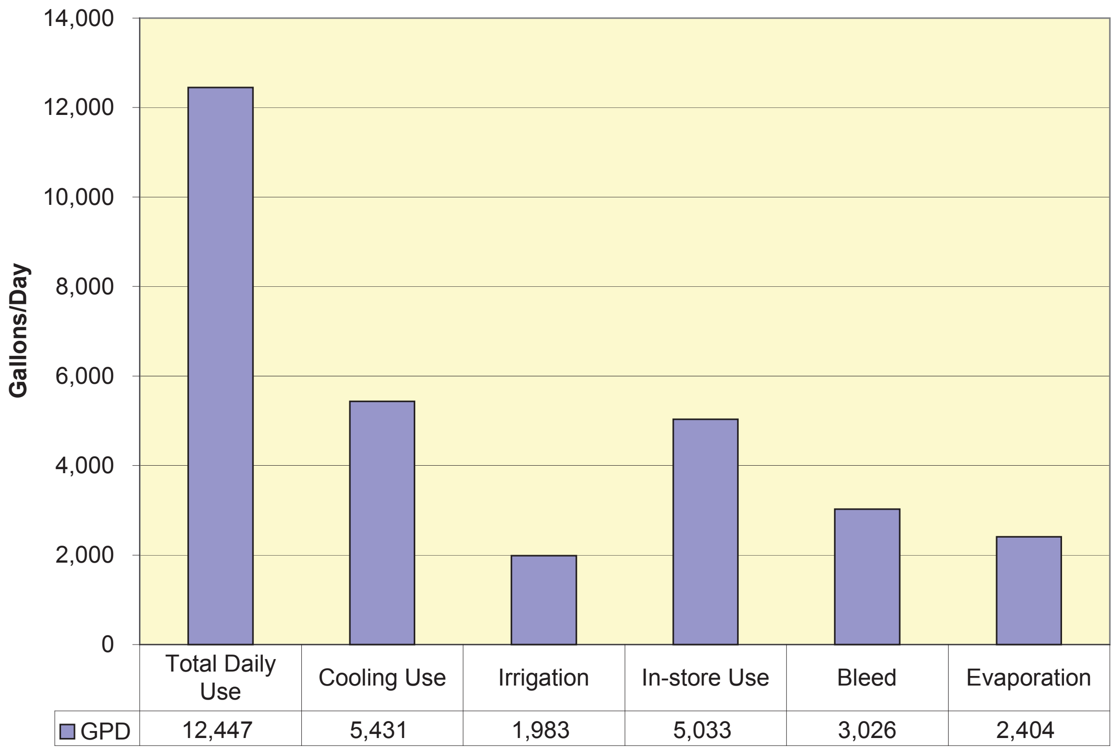


Figure 21: Average daily water use at Santa Monica

There is a considerable amount of variation in the daily water use, which is shown in Figure 22. These data were obtained from the data logs on the main meter and EC controller and were summarized on a daily basis for the June 2 to July 11th period. It is interesting to note how strongly changes to the cooling use influence use at the store, even when irrigation use is included. The total water use at the store parallels the gradually decreasing use for cooling from June 2nd to the 28th, and then drops on the 29th when a change was made to the setting of the cooling bleed rate, or a leaky bleed valve is repaired. Over this period the cooling water use dropped by 4,500 gpd (from 7,500 gpd to around 3,000 gpd) and the total store use dropped by almost the same amount from 14,000 gpd to 10,000 gpd. This shows that reductions in the cooling use were reflected very clearly in reductions in the overall store use. It should be kept in mind that the changes in cooling use at this store were due to adjustments made by the water treatment company as part of their maintenance, and do not reflect changes from the new water treatment process, which did not occur until October, 2002.

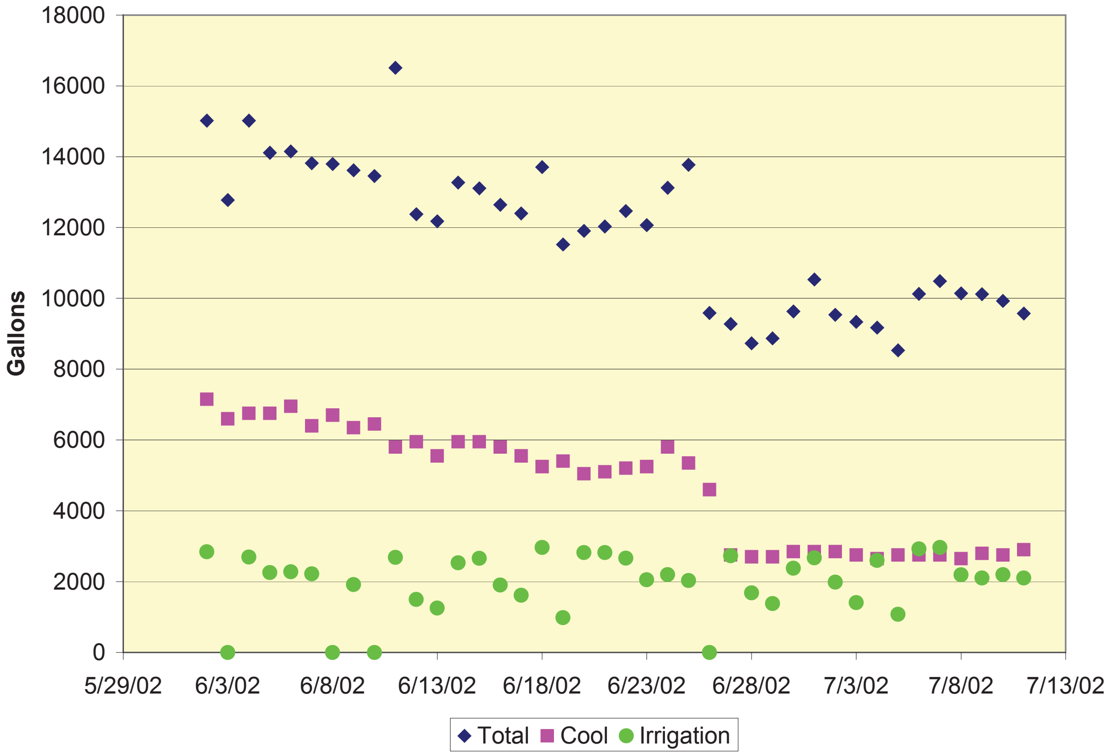


Figure 22: Daily Use at Santa Monica During Logging Period

Hourly Use at Santa Monica

When the data from the loggers was summarized on an hourly basis it was possible to average the water use for each hour of the day and show how the in-store, irrigation, and cooling water use in the store varies over a typical 24 hour period. This information is shown in Figure 23. During the period for which logging data were available it can be seen that the cooling water use stayed very close to 200 gallons per hour (3.33 gpm) over the day. The biggest peak can be seen between 3:00 and 6:00 am, when irrigation was occurring. After 6:00am, the in-store use remained between 500 and 350 gallons per hour.

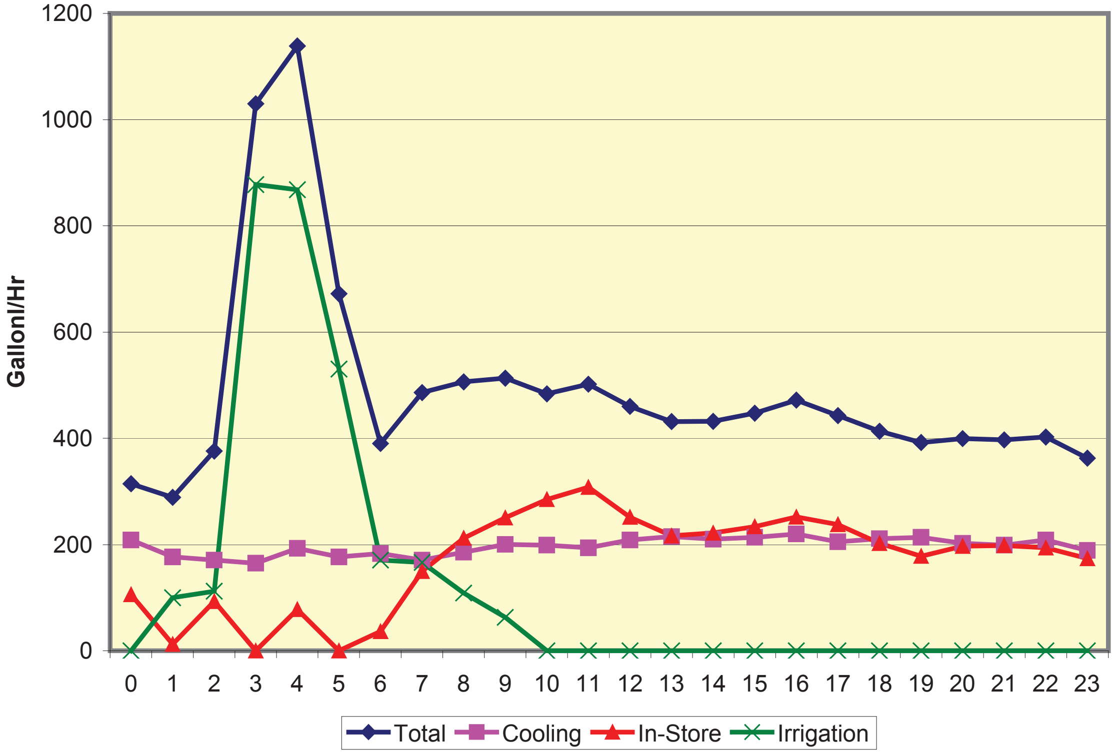


Figure 23: Hourly Water Use at Santa Monica

Sun City

Annual and Monthly Baseline Use

During the 21 month period from Jan 2001 to September 2002, the Sun City store used a total of 3,339 kgal of water (3.3 million gallons). As shown in Table 16 and Figure 24, water use mainly stayed between 100 and 200 kgal per month.

Table 16: Monthly Water Use at Sun City

Month	Use (kgal)	Percent of Total
Jan-01	176	5%
Feb-01	174	5%
Mar-01	162	5%
Apr-01	125	4%
May-01	170	5%
Jun-01	175	5%
Jul-01	162	5%
Aug-01	180	5%
Sep-01	207	6%
Oct-01	177	5%
Nov-01	183	5%
Dec-01	122	4%
Jan-02	135	4%
Feb-02	128	4%
Mar-02	116	3%
Apr-02	122	4%
May-02	135	4%
Jun-02	141	4%
Jul-02	163	5%
Aug-02	200	6%
Sep-02	186	6%
Total	3339	
Ave Month	159	
Ave Day	5.30	

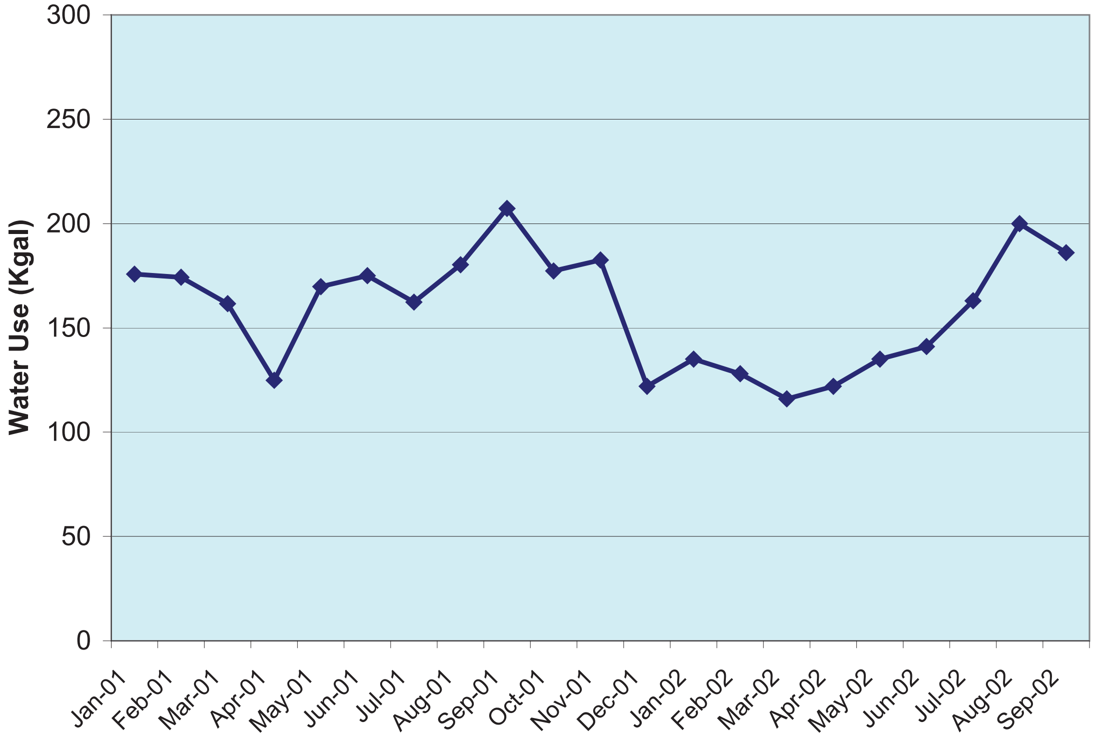


Figure 24: Baseline water use at Sun City

Daily Use During Baseline Period

The average daily use is broken down in Figure 25 for the baseline period. This shows that during the April through October period the average daily use for the store as a whole was 5,389 gpd. Out of this, 3,032 gpd (56%) were used for make up to the cooling tower. Of the make up, 1,399 gpd were measured by the bleed meter leaving 1,633 gpd was for evaporation. Based on the ratio of the bleed water to the make up water, the average cycles of concentration of the cooling water was around 2.1 during this period.

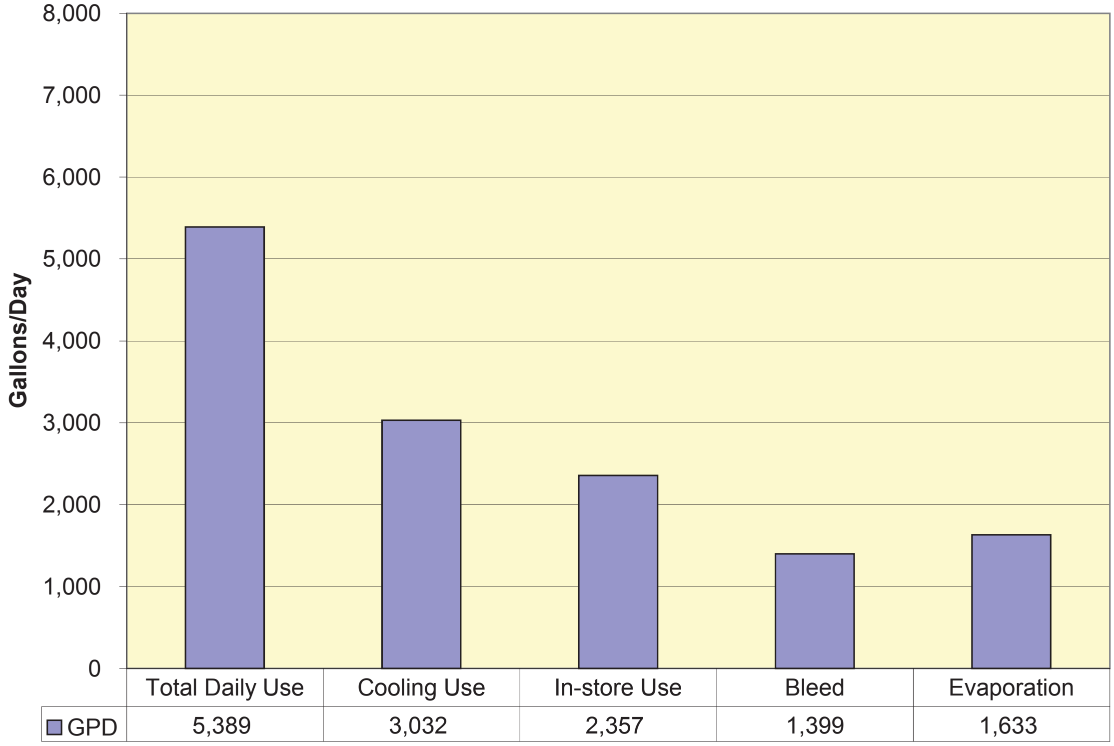


Figure 25: Average daily water use at Sun City (4/28/02 – 10/7/02)

A look at Figure 26 shows that the cooling use and the total store use followed roughly the same pattern over the logging period. The cooling use mainly stayed between 3 and 4 kgal, and the total store use stayed mainly between 6 and 7 kgal. All in all, the ratio between total cooling use and total store use stayed quite constant. This suggests that changes in total cooling use will likely be reflected in total store use.

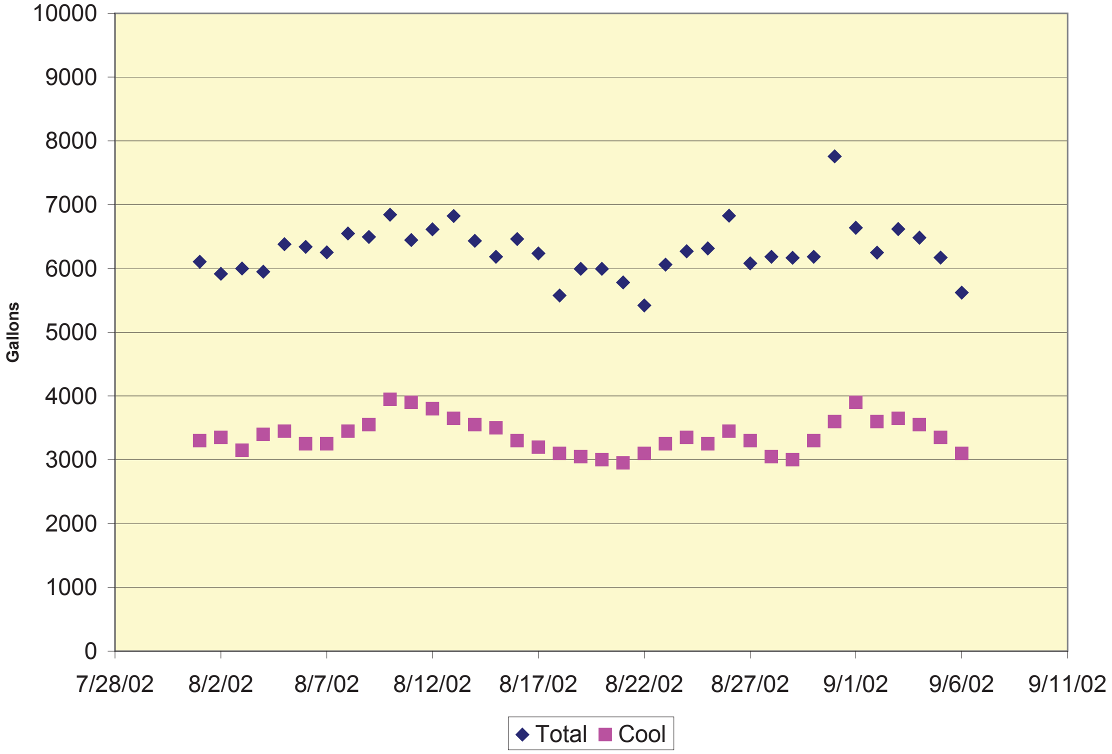


Figure 26: Daily use at Sun City store

Hourly Use at Sun City

When the data from the loggers was summarized on an hourly basis it was possible to average the water use for each hour of the day and show how the in-store and cooling water use in the store varies over a typical 24 hour period. This information is shown in Figure 27. During the period for which logging data were available it can be seen that the cooling water use stayed roughly between 100 and 200 gallons per hour over the day. The in-store use began ramping up at 6:00 am, reached its peak around 3:00pm, and then gradually decreased.

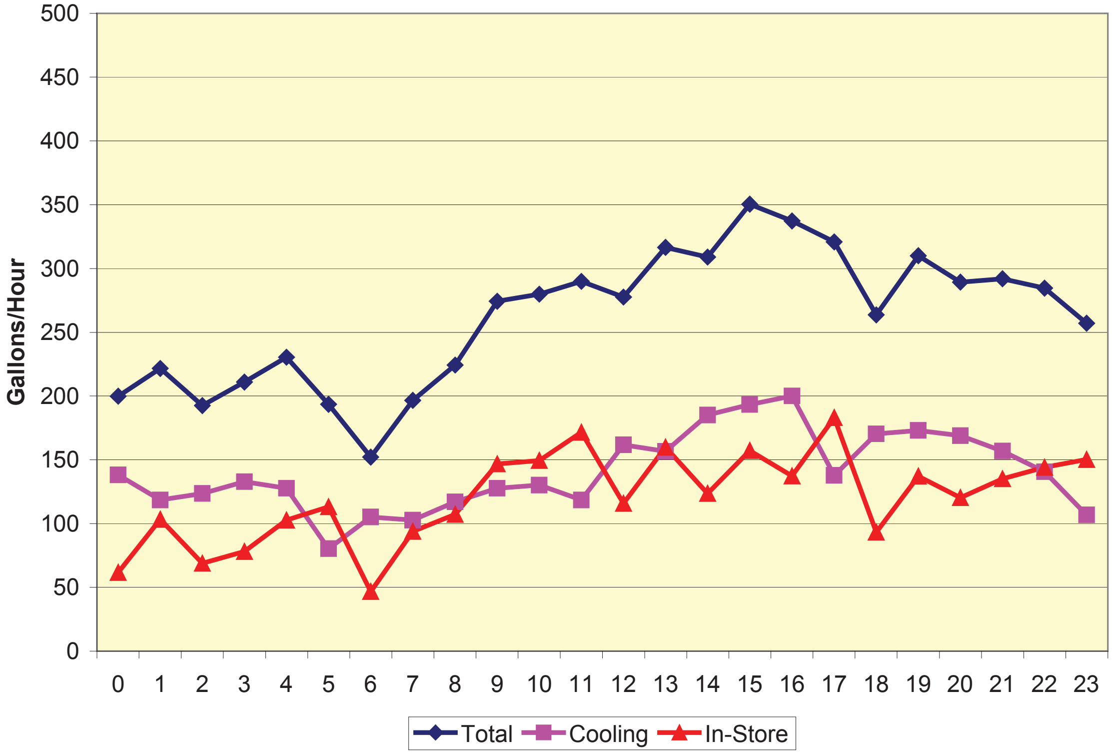


Figure 27: Hourly Water Use at Sun City

USC

Annual and Monthly Baseline Use

During the 21 month period from Jan 2001 to September 2002, the USC store used a total of 5,971 kgal of water (6.0 million gallons). As shown in Table 17 and Figure 28, water use mainly stayed between 200 and 350 kgal per month.

Table 17: Monthly Water Use at USC

Month	Use (kgal)	Percent of Total
Jan-01	224	4%
Feb-01	242	4%
Mar-01	276	5%
Apr-01	254	4%
May-01	328	5%
Jun-01	308	5%
Jul-01	349	6%
Aug-01	283	5%
Sep-01	311	5%
Oct-01	261	4%
Nov-01	283	5%
Dec-01	220	4%
Jan-02	301	5%
Feb-02	246	4%
Mar-02	269	5%
Apr-02	259	4%
May-02	275	5%
Jun-02	296	5%
Jul-02	364	6%
Aug-02	295	5%
Sep-02	327	5%
Total	5971	
Ave Month	284	
Ave Day	9.48	

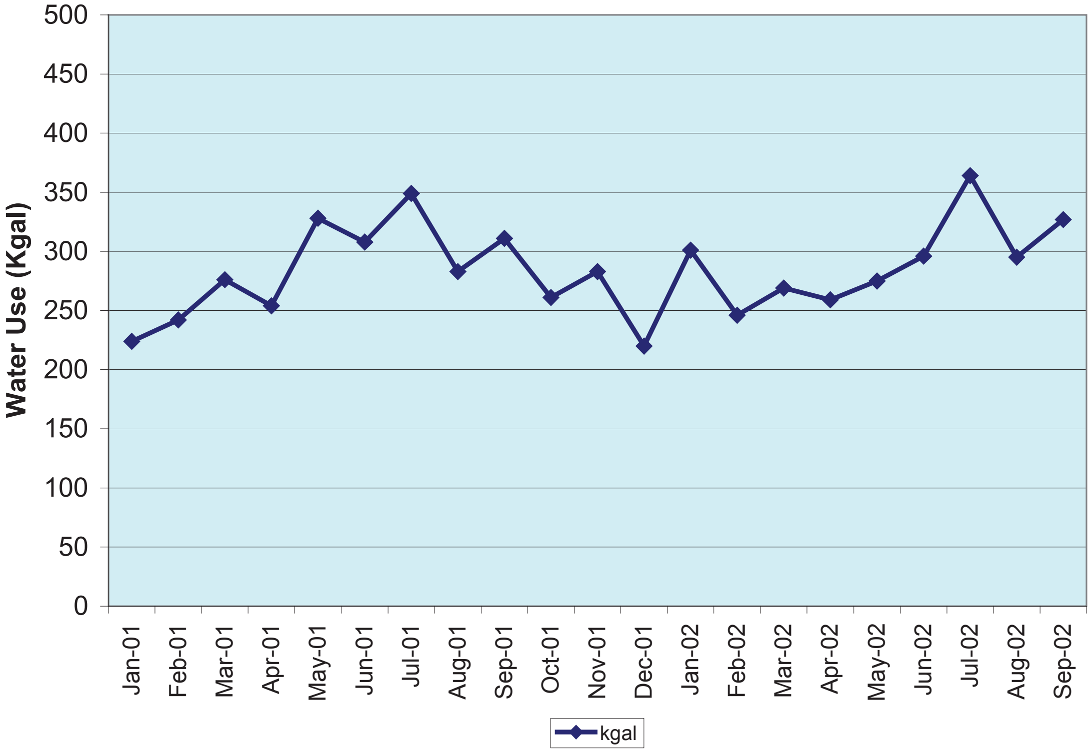


Figure 28: Baseline water use at USC

Daily Use During Baseline Period

The average daily use is broken down in Figure 29 for the baseline period. This shows that during the April through October period the average daily use for the store as a whole was 8,948 gpd. Out of this, 4,347 gpd (49%) were used for make up to the cooling tower. Of the make up, 1,859 gpd were measured by the bleed meter leaving 2,489 gpd was for evaporation. Based on the ratio of the bleed water to the make up water, the average cycles of concentration of the cooling water was around 2.3 during this period.

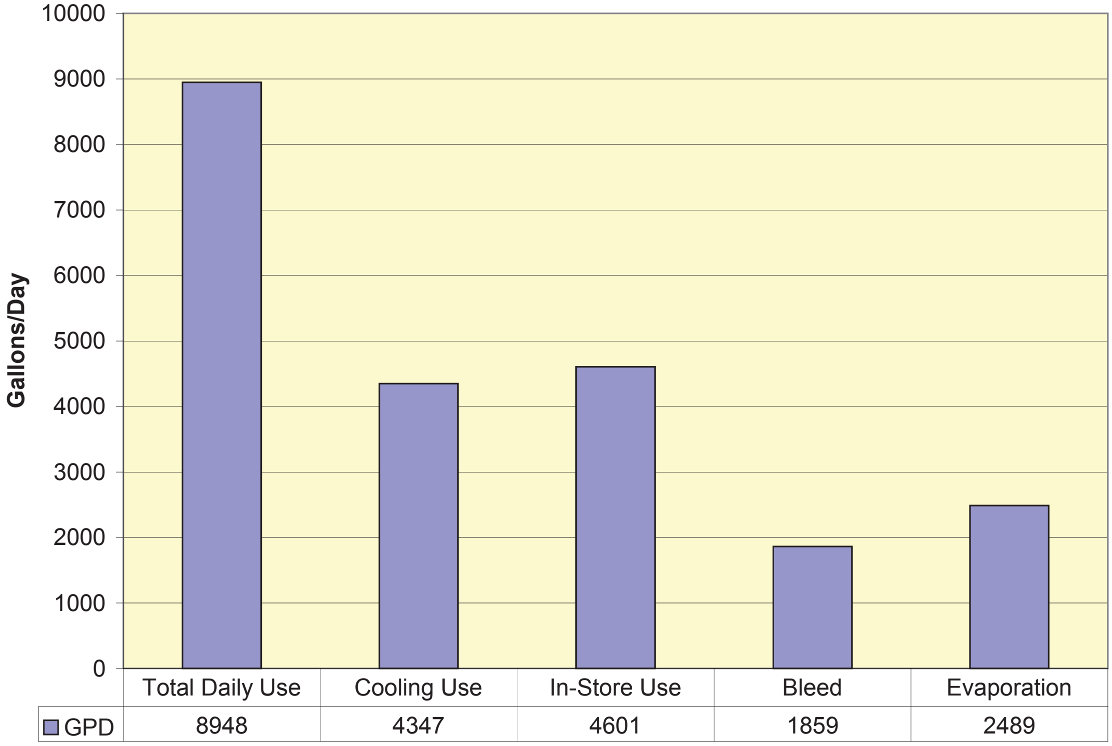


Figure 29: Average daily water use at USC (4/29/02 – 10/7/02)

A look at Figure 30 shows that the cooling use and the total store use followed roughly the same pattern over the logging period. In the first half of the logging period, cooling use ranged between 2,500 and 4,200 gallons and the total daily use ranged mainly between 8,000 and 11,000 gpd. After that, there are three outlying cooling points above 6,000 gallons that correspond with total store use points above 13,000 gallons. After that, the cooling stayed in a range between 3,600 and 6,000 while the total cooling ranged from about 9,000 to 12,000. All in all, the ratio between total cooling use and total store use stayed quite constant. This suggests that changes in total cooling use will likely be reflected in total store use.

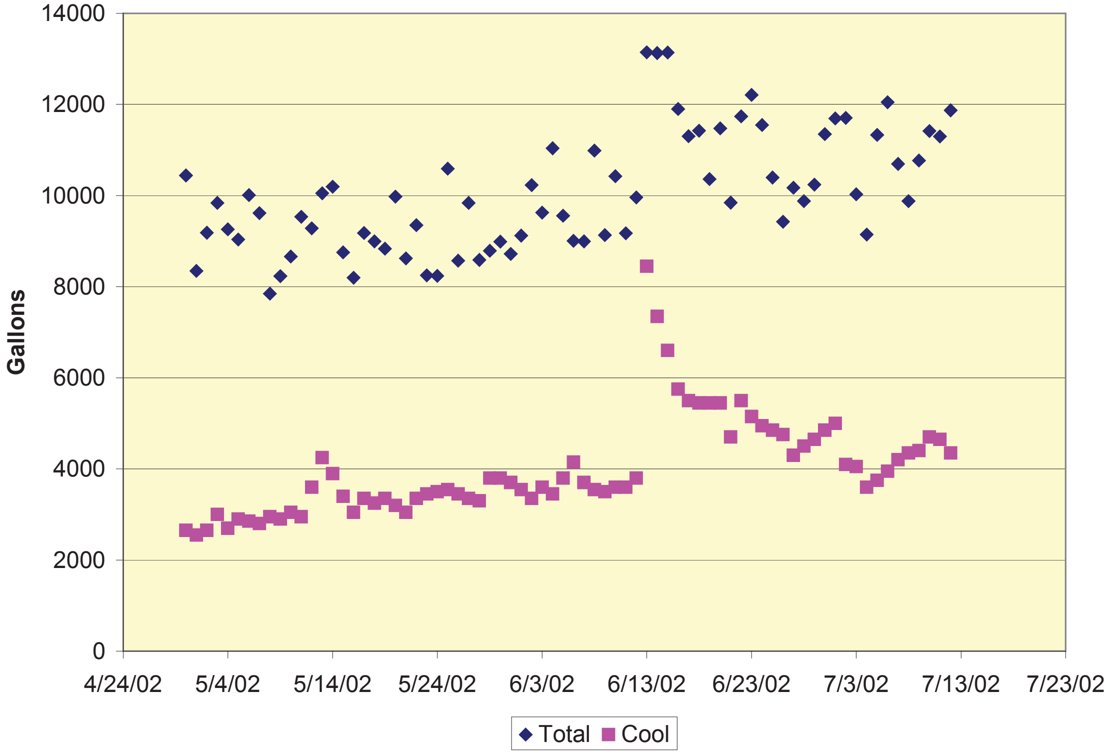


Figure 30: Daily use at USC store

Hourly Use at USC

When the data from the loggers was summarized on an hourly basis it was possible to average the water use for each hour of the day and show how the in-store and cooling water use in the store varies over a typical 24 hour period. This information is shown in Figure 31. During the period for which logging data were available it can be seen that the cooling water use stayed roughly between 100 and 200 gallons per hour over the day. The in-store use began ramping up at 2:00 am, reached its peak around 8:00pm, and then sharply decreased until midnight.

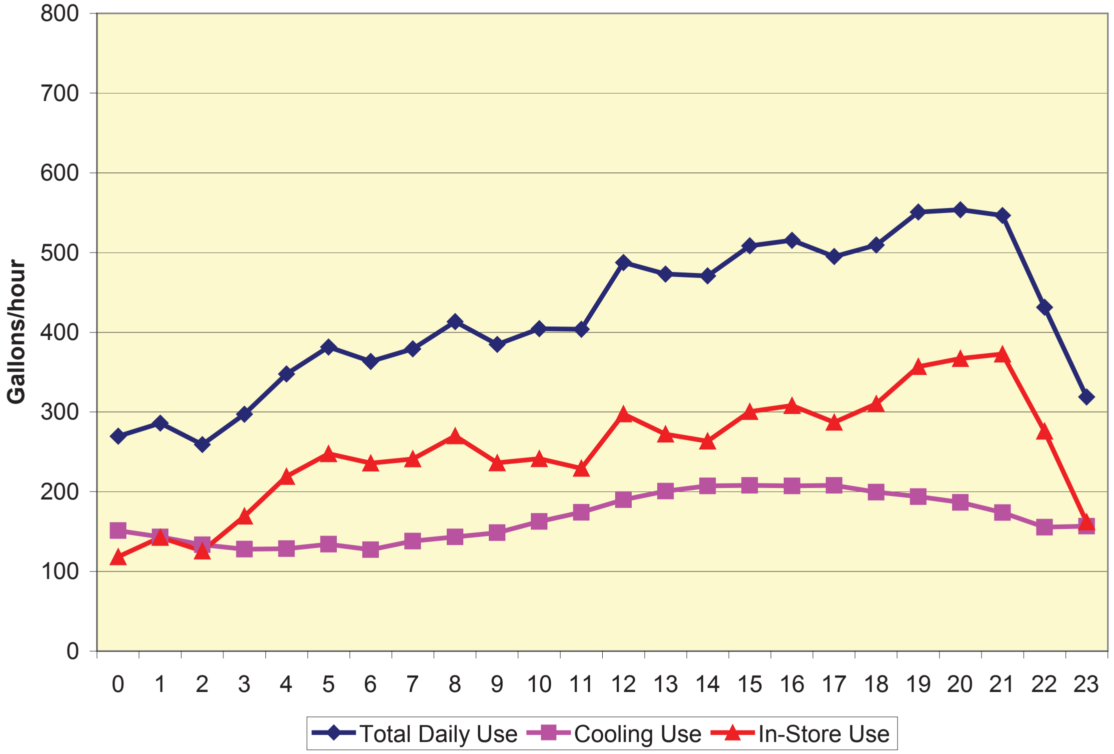


Figure 31: Hourly Water Use at USC

Summary of Baseline Use at Six Stores

In order to easily compare the baseline water use at all six stores the summary data are presented together in Table 18. These data are shown graphically in Figure 32. The average water use for all the stores is 3.5 million gallons per year, and this ranges from a low of 1.9 million gallons in Sun City to a high of 5.1 million gallons in Beverly. On a daily basis the stores used approximately 10 kgal per day, which is about as much as a family of four uses in 2 to 3 months for indoor purposes. The range in daily use went from a low of 5 kgal per day in Sun City to nearly 14 kgal at Beverly.

These data show that there is much more variability in the in-store water use than in the cooling use. The Arcadia and Sun City stores had the fewest departments and in-store services and also had the lowest in-store water use. Their cooling use, however, is much closer to that of the other stores. The Beverly, Irvine and Santa Monica stores had the most in-store services and cooking also used the most water.

Table 18: Summary of Baseline Water Use at All Stores (kgal)

	ARC	BEV	IRV	SC	SM	USC	Average
Water Meter Data							
Annual Use	2244	5064	4044	1908	4512	3408	3530
Ave Month	187	422	337	159	376	284	294
Ave Day	6.15	13.85	11.25	5.3	12.53	9.48	9.76
Daily Use During Logging							
Total Daily Use	4.924	9.047	10.734	5.389	12.447	8.948	8.582
In-Store Use	1.313	4.596	6.867	2.357	5.033	4.601	4.128
Total Cooling Use	3.61	4.451	3.867	3.032	5.431	4.347	4.123
Bleed	0.973	1.283	1.547	1.399	3.026	1.859	1.681
Evaporation	2.638	3.168	2.320	1.633	2.404	2.489	2.442

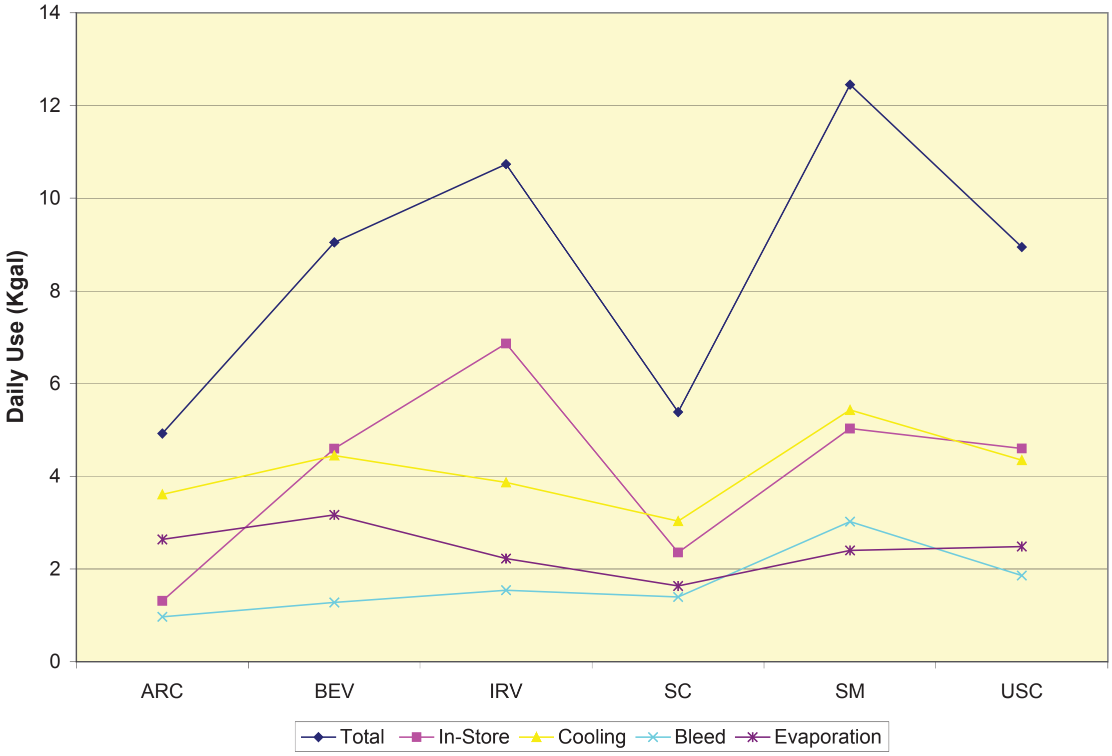


Figure 32: Summary of baseline water use at all stores

BASELINE ENERGY USE

The electrical consumption followed the same pattern as did the water consumption. The Sun City and Arcadia stores used the least electricity and the Irvine and Beverly stores used the most. The USC store was in the middle. No electrical data were available for the Santa Monica store, so it was excluded.

As shown in Table 19, In 2001 the stores used an average of 2.3 million kWh each, and this ranged from a low of 1.4 million in Arcadia to a high of 3.3 million in Irvine. The average monthly energy use at the stores was 194,000 kWh, around as much as 15 families normally use in a year.

The monthly energy use is shown in Figure 33. The most striking thing about these data is the virtual lack of summer energy peaking shown in the stores. This parallels the lack of peaking in water use.

Table 19 : Baseline electrical consumption for five stores (kWh)

2001	**Sun City**	**Irvine**	**Arcadia**	**Beverly**	**USC**	**Average**
Total Annual	1,671,120	3,295,477	1,421,174	2,919,168	2,333,280	2,328,044
Avg. Month	139,260	274,623	118,431	243,264	194,440	194,004
Std. Dev.	8,704	23,348	9,022	16,025	15,822	14,584

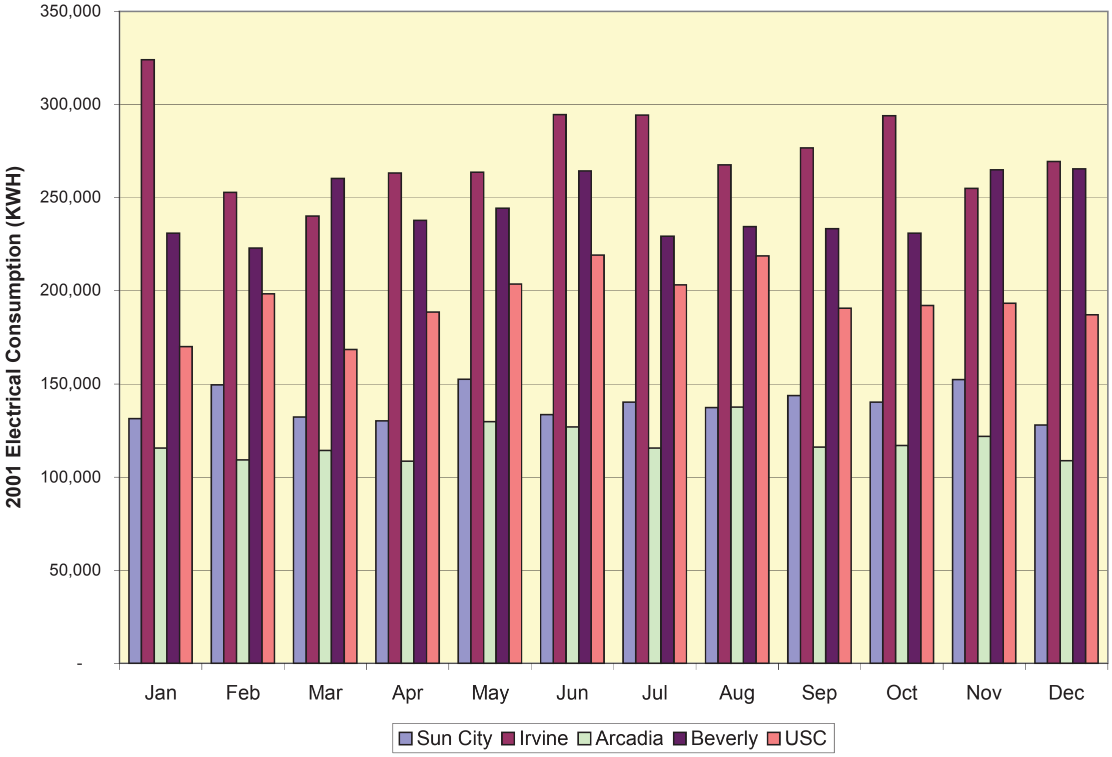


Figure 33: Baseline energy consumption for five stores

Energy consumption is a potential factor for this study because the major electrical consumer in the stores is the refrigeration system, and there is a direct relationship between the energy required to run the refrigeration compressors and the efficiency of the coolers. Any scale present on the tube bundles will reduce the cooling efficiency. This in turn causes the refrigerant to be warmer when it returns to the compressors, which, then requires the compressors to use more energy to condense it back to a liquid. At a certain point the refrigerant can become too warm for the compressors, and the system will shut down. A failure of the refrigeration system is a major emergency in supermarkets given the fact that they normally contain over $200,000 in refrigerated or frozen inventory.

OPPORTUNITIES FOR WATER CONSERVATION

There are three basic approaches to saving water in any facility: teach people to change their water using habits, install more efficient water using fixtures and technologies, repair leaks and defective fixtures and devices. In most supermarkets all three approaches are applicable, however, the main opportunity lies in the cooling system, because this uses the most water.

Cooling Water

In most supermarkets the main cooling load is handled by an evaporative condenser. This is similar to a cooling tower, but has a major difference. In a cooling tower the circulating water is run through the tower and out to a heat exchanger elsewhere in the mechanical system of the building. The cooling water does not come into direct contact with the equipment being cooled (except via whatever type of heat exchanger is involved in the process). In an evaporative condenser the heated refrigerant is run into the top end of the unit where water is sprayed over the coils and a fan blows air through the mist to cool the refrigerant by evaporating some of the water. The fact that the cooling water comes into direct contact with the condenser coil is the most important difference between an evaporative condenser and a cooling tower.

From a water use perspective, the operation of an evaporative condenser is essentially the same as that of a cooling tower. A pool of water circulates in direct contact with the air in order to absorb heat from some other fluid through direct conduction (heating a volume of air to the same temperature of the refrigerant) but primarily evaporation. Water enters the system from the potable water supply and leaves via evaporation, blowdown and drift.

Water Balance of an Evaporative Condenser

The water balance of a cooling tower has been described well by Kobrick and Wilson (1993)[2]. Makeup Water (M) enters the evaporative condenser from the city system in order to replace water lost through evaporation (E), drift (D) and blowdown (B).Using this notation it can be seen that the basic water balance equation can be written as:

$$M = E + B + D \quad (1)$$

But it is known that drift is small relative to evaporation and blowdown, and since it contains solids it can be considered as part of the blowdown. So the equation can be simplified as:

$$M = E + B \quad (2)$$

From the standpoint of dissolved solids in the system, it is known that the evaporation water is pure water vapor and contains no salts. So, at steady state, the mass of solids flowing into the system with the makeup water must equal the mass of solids leaving the system with the blowdown water, which is the same as the water circulating in the system. Since the mass of solids in a volume of liquid equals the concentration times volume, the solids concentration of the makeup water times the volume of makeup water in a given time period must equal the concentration of the blowdown water times the volume of blowdown water in the same time period for the solids balance to hold. Mathematically this means,

$$CM \times M = CB \times B \quad (3)$$

The term, concentration ratio, is used to describe the ratio of the concentration of the blowdown water to that of the makeup water, or

$$CR = CB/CM \quad (4)$$

It follows then that at steady state for the solids balance to hold the concentration ratio must also equal the ratio of the volume of makeup water to the blowdown, or

$$CR = M/B \quad (5)$$

What equation 5 is saying is that as the system is operated at higher cycles of concentration the volume of blowdown water must become a smaller and smaller fraction of the water entering the system for makeup. As explained by Kobrick there are several ways to rearrange these equations:

$M = CR \times B$ ……………………………………………………….(6)

$B = M / CR$

$B = (E + B)/CR$

Or,

$B = E/ (CR - 1)$ ………………………………………………………(7)

Using Equations 2 and 7 it is possible to estimate the amount of blowdown and total water use needed to maintain a given concentration ratio for a constant evaporation rate. It is known that evaporation is fairly constant as a function of the heat load on the system.

By definition, 1 ton of cooling equals 12,000 BTU per hour or 288,000 BTU per day. So, a 100 ton heat load to a cooler requires transfer of 2.88×10^7 BTU/day into the atmosphere. In order to do this requires evaporation of 3,560 gallons of water, since the latent heat of water is 8,100 BTU per gallon evaporated. If it is assumed that 10% of the heat is transferred by convection to the atmosphere this reduces the evaporation rate to 3200 gal/day. Using equations 2 and 7 allows us to calculate the total water required by a 100 ton cooling load as a function of the concentration ratio of the system which is shown in Figure 34.

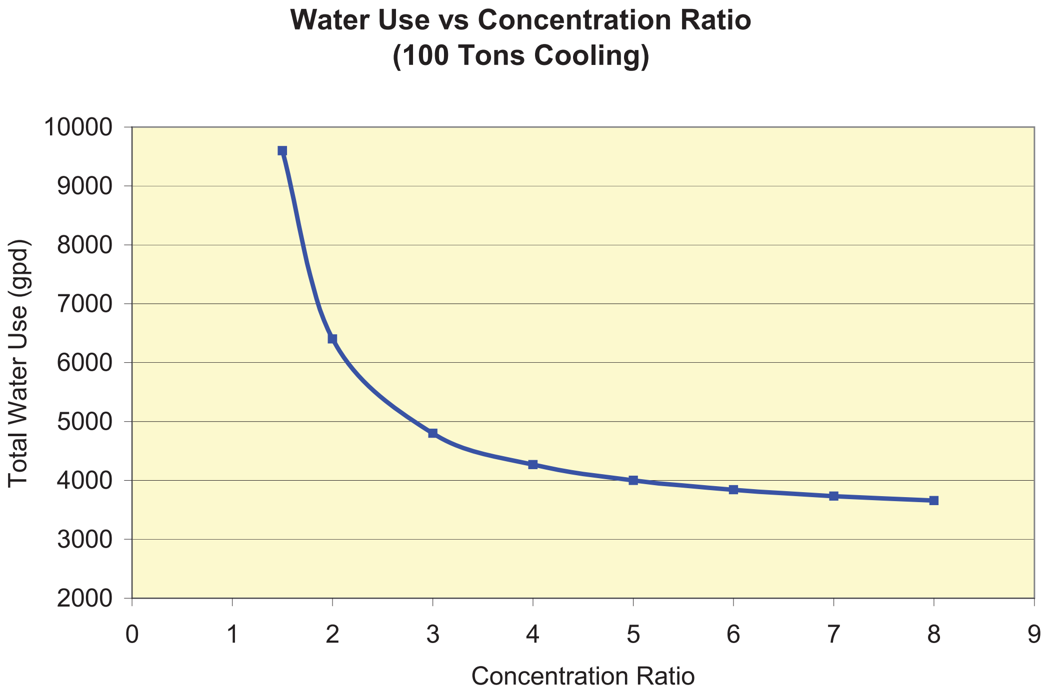


Figure 34: Water Requirement VS. Concentration Ratio for 100 T Cooling Load

Manufacturers often recommend that blowdown be set equal to 3 gpm per 100 tons of cooling load.[3] Using this criteria would result in a total water use of approximately 7,520 gallons per day, which is 4,320 for blow down and 3,200 for evaporation. This is equivalent to a concentration ratio of approximately 1.75, as shown in Figure 34, which shows that the corresponding concentration ratio for 100 tons of cooling with a water use of 7500 gpd is approximately 1.75. At this concentration ratio the annual water use for cooling would equal 2.7 million gallons. If the same system were operated at a concentration ratio of 6 the daily water requirement would drop to approximately 3,840 gallons, and the annual use to 1.4 million gallons, for a savings of 1.3 million gallons of water. This explains the interest in more efficient operation of evaporative coolers by the water supply industry, and the potential for savings in water and wastewater charges to the owners.

Saving Potential in Study Stores Cooling Systems

The baseline water use data contains direct information on the evaporation rates and concentration ratios for all six stores. Using this information the actual potential water savings for these stores can be calculated as they change from their starting concentration ratios to the target concentration ratio of 6.0. Table 20 shows the results of these calculations.

The first thing that stands out in this table is that the actual heat loading to these systems as calculated from the observed evaporation rates is much lower than the rating of the towers. The percent of the rated capacity at the stores ranges from a low of 31% at the Santa Monica store. The average actual loading to the evaporative condensers at the six stores was approximately 75 tons while their average rated capacity was 188 tons, so these systems are running at approximately 40-46% of their rated capacity during the baseline period, on average.

Using the theoretical calculations, it looks reasonable to anticipate reductions in water use at these facilities by an average of 1330 gpd or 486 kgal per year (1.79 ccf/day or 649 ccf/yr). The actual savings achieved in the study, as explained below, proved to be greater than the theoretical.

Table 20 : Potential Saving from cooling in six study stores

Store	Rating	Evaporation	Actual	%	CR1	Bleed1	CR2	Bleed2	Savings	Savings
	(Tons)	(gpd)	(Tons)			(gpd)		(gpd)	(gpd)	(kgal/yr)
ARC	120	2638	82	68	3.71	973	6	377	596	218
BEV	200	3168	98	49	3.47	1283	6	453	830	303
IRV	200	2320	72	36	2.50	1547	6	331	1216	444
SC	80	1633	51	64	2.17	1399	6	233	1166	425
SM	240	2404	75	31	1.79	3026	6	343	2683	979
USC	285	2489	77	27	2.34	1859	6	356	1503	549
AVE	188	2442	75	46	2.66	1681	6	349	1332	486

In-Store Use

These stores typically contain from 30 to 50 water using fixtures and appliances. Some of these use water in a very consistent pattern based on the nature of the fixture. For example toilets and urinal water use does not vary in normal use from event to event. The water use of others, however, is dependent on how the human controlling them decides to use them. The regular fixtures can save water by being the most water conserving type available (i.e. ULF devices). The human controlled devices can be either flow sensitive or volume sensitive. The biggest potential water savings opportunities that were observed in theses stores came in areas where there were flow sensitive water uses rather than volume sensitive. For example, most of the hand faucets in the stores had either no aerators or old and damaged aerators that allowed flow rates that were much greater than necessary. These could all be changed to high efficiency low flow aerators in combination with flow restricting devices on the feed lines. These are needed because the aerators are frequently removed by the employees. An example of a volume sensitive water use is in the use of three compartment sinks for pot washing for food preparation. These typically hold from 20 to 30 gallons of water and are filled up several times per day for washing or food preparation. Installing flow restrictors or aerators on these sinks would only add to the time required to fill them. The way to reduce water use by these sinks is to adopt practices that require less washing of pots or water for food preparation. For example scraping of dirty dishes rather than spraying them down would eliminate a lot of water use.

Repairing leaks in faucets and replacing missing aerators should be a part of routine maintenance. Employees should be encouraged to report all leaks and other activities that are water wasting. Rewards and acknowledgments for these report should be provided.

Use of garbage grinders is a major water use in supermarkets. These typically use 7 gpm of water and are run for 2 to 3 hours per day[2]. Each grinder can account for over 1000 gallons of water use per day. Most of the stores had retired their grinders and were either composting their produce waste or hauling it to landfills.

---

[2] According to interviews with produce personnel.

Every store had a meat department, but the amount of water used for washing varied dramatically. The Irvine store used the most water for meat department washing, devoting up to 2000 gallons per day to this activity. They used a standard low pressure hose for this and hand sprayer. There was a high pressure washer installed, but it did not work properly and its flow rate was too low to be of practical use. If an effective high-pressure washer could be installed it might cut water use for washing in half. Also, a great deal of the washing of this facility could be done with a bucket and mop, and the spray could be reserved just for rinsing.

Thawing food under running water was not uncommon. If food could be thawed in a refrigerator over-night it would reduce this type of water use significantly.

Educating employees to use water wisely and to report waste and leaks is critical to a successful water conservation program in supermarkets. The fact that so many of the aerators that were installed had been removed within one month shows the low priority given to this topic by the employees. At the same time installation of good quality sprayers and aerators will reduce the temptation to remove them because high quality devices will provide a good spay pattern that will not need to be removed.

COOLING WATER BASICS

Dissolved solids present no problem with respect to the cooling capacity of water, since the evaporation rate of seawater, which has 30,000 ppm total dissolved solids, is only 1% less than that of distilled water. The problem with dissolved solids is that many of the chemical compounds and elements in the water will combine to form highly insoluble mineral deposits on the insides of the cooling towers and the cooling tube bundles. There are many different compounds that can contribute to this problem, but they are generally referred to as “scale”. The primary maintenance objective in most cooling towers, therefore, is to minimize the formation of scale deposits.

Next to scale, the next most important concern in most cooling systems is the prevention of corrosion to the metal components of the system consisting most commonly of stainless steel, copper, soft steel and zinc (listed in decreasing order of corrosion potential). Warm, moving water with high dissolved solids concentrations can be an extremely corrosive environment, and care needs to be taken to minimize the potential for corrosion in cooling systems. It is often a fine line between scale and corrosion.

Elimination of biological fouling and prevention of the incubation of pathogens forms the third leg of the cooling tower water management triangle. There are many species of algae, protozoa, and bacteria that can thrive in cooling systems under certain circumstances. These include mere nuisances and life threatening infectious agents like the bacteria Legionella pneumophillus.

Scale Prevention

Entire textbooks have been devoted to this subject, but for our purposes only a few key points need emphasis.

Important Ions and Compounds

The key cations with respect to scale formation. in most waters are Calcium (Ca^{+2}) and Magnesium (Mg^{+2}), while the key anions are bicarbonate (HCO_3^-), carbonate (CO_3^{-2}), sulfate (SO_4^{-2}) and silicate (SiO_3^{-2})

Hardness is important since it provides a measure or the amount of calcium and magnesium in the water. Technically any bi-valent metal ion such as iron, manganese or tin would constitute hardness, but calcium and magnesium are the two most prevalent forms. The relative solubilities of the scale forming compounds in water are shown in Table 21. All of these compounds are soluble in acid solutions.

Both calcium and magnesium carbonates are only sparingly soluble in water. Since these are the two most prevalent hardness cations, and carbonate is the most prevalent form of alkalinity then it follows that the most prevalent forms of scale are calcium and magnesium carbonates (calcite and dolomite). Water with high levels of Silica, however, can form the very insoluble magnesium silicate scale, so special precautions are needed in these cases. In cases where sulfates are high, or where sulfuric acid is being fed for alkalinity control, calcium sulfate (gypsum) can be a problem.

Table 21: Relative solubility of scale compounds in water (pH 7+)[3]

Cations ➔ **Anions ➔**	**Ca $^{+2}$**	**Mg $^{+2}$**
Carbonate (CO_3^{-2})	Sparingly	Sparingly
Silicate (SiO_3^{-2})	Sparingly	Insoluble in water
Phosphate (PO_4^{-2})	Sparingly	Sparingly
Sulfate (SO_4^{-2})	Sparingly	Soluble

The Role of Alkalinity

Alkalinity plays a key role in scale formation. In most cases the primary scale reaction involves the formation of either calcium or magnesium carbonates. In virtually all municipal water supplies the dominant form of alkalinity in the water is in the bicarbonate form. As the pH rises above 8.3, however, there is a dramatic shift from the bicarbonate to the carbonate form, and this is precisely the least soluble form for calcium and magnesium. At pH values less than 8.3 most of the alkalinity in the water is in the bi-carbonate form, and calcium and magnesium scale formation is normally not a problem. When the pH rises above 8.3, however, the alkalinity converts to the carbonate and scaling will occur. This shifting of alkalinity forms can be seen in Figure 35. This shows that for the range of pH of concern, that the key value is 8.3, which is the point of inflection between the carbonate and bi-carbonate form of alkalinity. When the pH rises above this level carbonate ions will dominate, and calcium and magnesium scale will start to form.

---

[3] From CRC Handbook of Chemistry and Physics, 2003

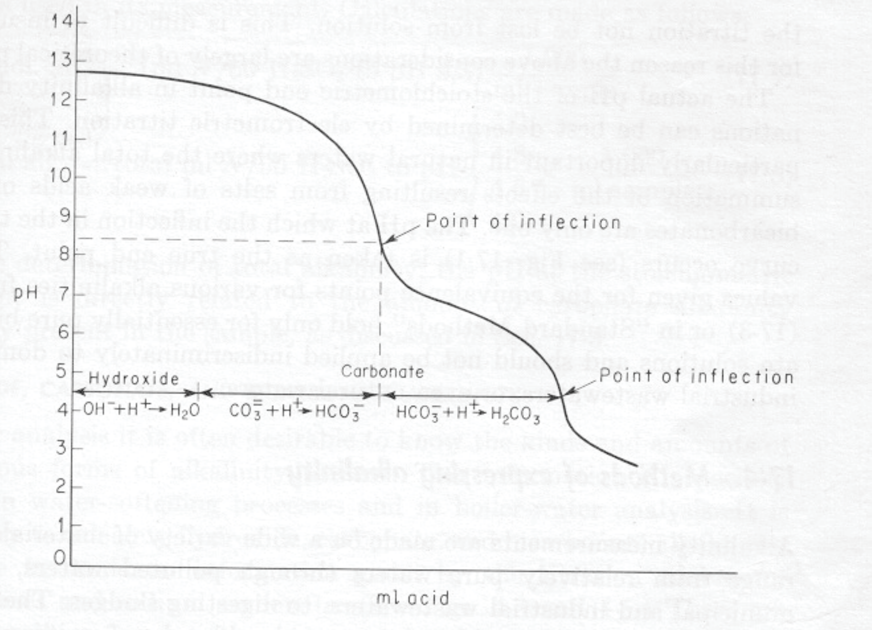


FIGURE 17·1 Titration curve for a hydroxide-carbonate mixture.

Figure 35: Alkalinity titration curve

Phosphate and Phosphonates

Many water treatment processes are based on the use of inorganic phosphates and organic phosphonates as threshold inhibitors for scale, and as corrosion inhibitors. Phosphates are of concern because they can cause scale. There are three varieties to consider: reactive orthophosphate, which is available in solution; acid hydrolizable phosphate, normally derived from various forms of poly-phosphates, and phosphates derived from oxidation of organic phosphonates in acidic solutions at high temperatures. Use of these chemicals must be closely monitored because at low levels they can inhibit scale formation, but at higher levels they can create scale problems of their own. An example of these potential problems is shown in Figure 36, which shows the relationship between calcium hardness, pH and orthophosphate levels and calcium phosphate solubility.

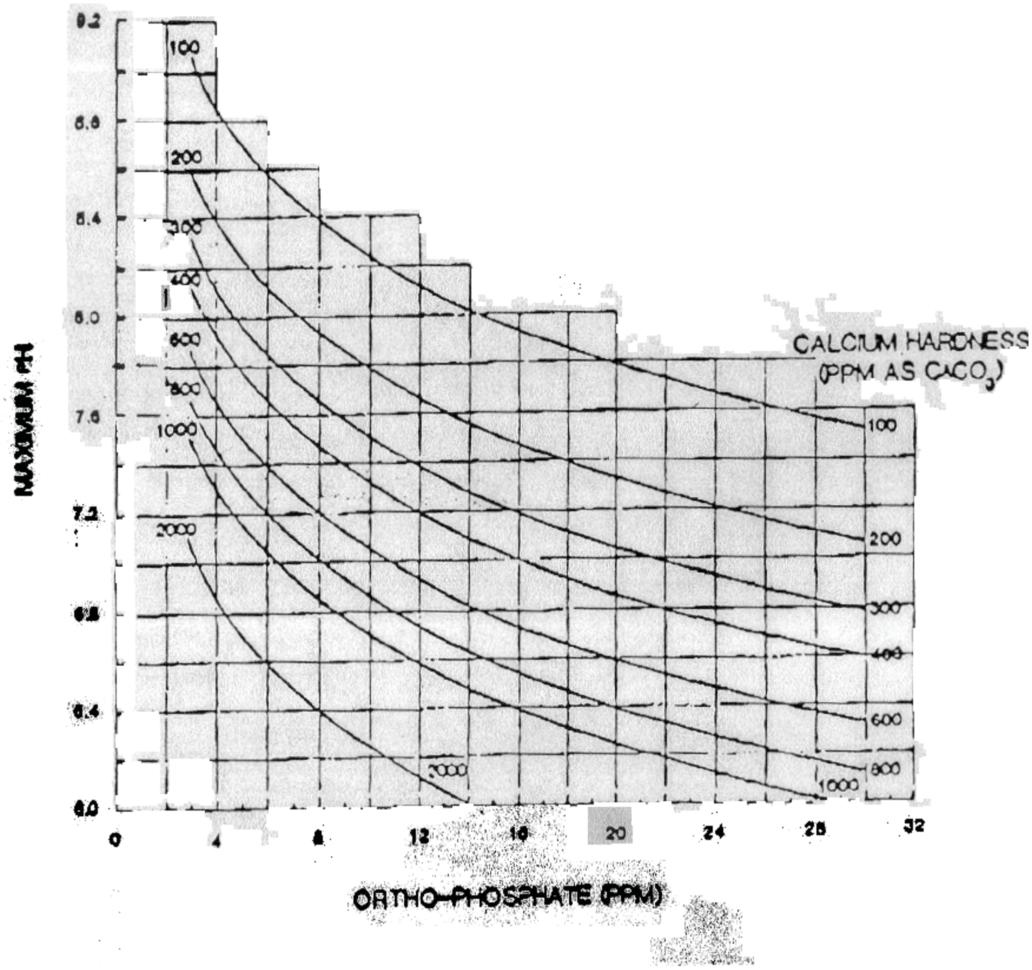


Figure 36: Calcium phosphate solubility chart

Source Chem Pro Laboratories.

Corrosion

In general, corrosion is a three step electrochemical reaction in which free oxygen in the water passes into a metal surface a one point (referred to as the cathode) and reacts with water and electrons, which have been liberated by the oxidation of metal at the anode portion of the reaction at another spot on the metal surface. The combination of free electrons, oxygen and water forms hydroxide ions. The hydroxide ions then combine with the metal ions, which were liberated at the anode as part of the oxidation reaction, to form an insoluble metal hydroxide. This process, with variations, continues at rates that are dependant on the availability of the reagents. Most corrosion control strategies involve coating the metal with thin films to prevent free oxygen and water from coming into close contact with the metal surface. This breaks the reaction cell, and reduces the corrosion rates. Figure 37 shows a typical coupon rack installation. Not shown in the picture is the flow meter installed above to insure that flow rates through the rack stay in acceptable limits.

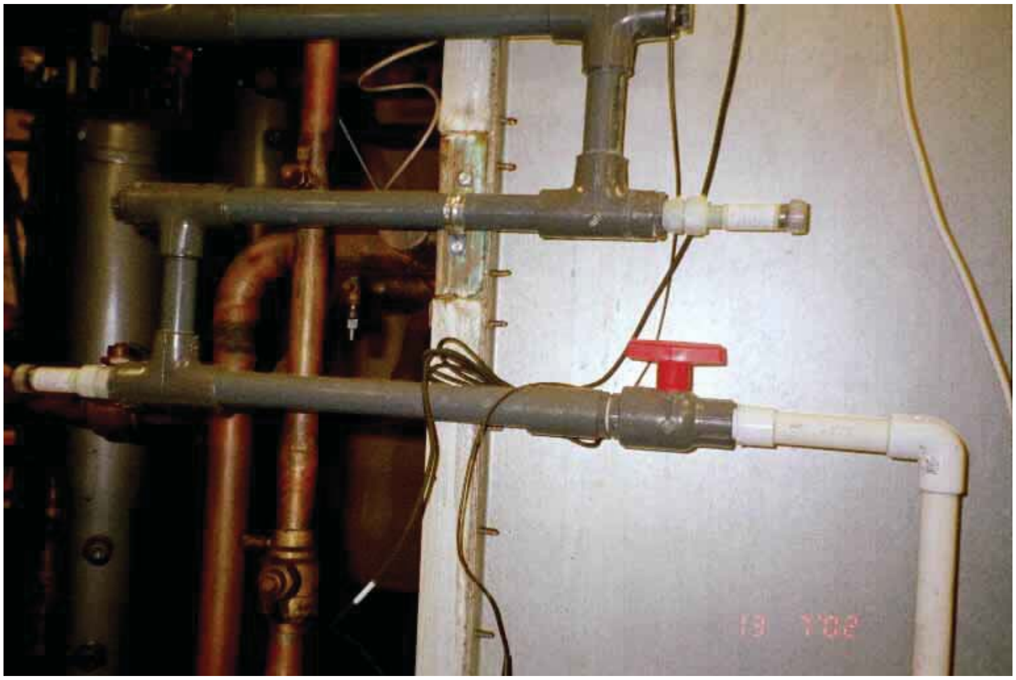


Figure 37: Coupon racks used for study

Corrosion rates are most commonly tested using metal coupons. Mild steel and copper coupons are frequently used since these represent the metals that are most vulnerable to corrosion in the system. The following table shows the ranges of corrosion rates, in mils/year[4] for metals in cooling systems.

Table 22: Corrosion rate standards

Rating	Rate (Mils/yr)
Poor	>5
Fair	3.5-5.0
Good	2.0-3.5
Excellent	0.0-2.0

---

[4] 1 mil = .001 inch

Biological Fouling

Biological fouling is important both for health and scale prevention reasons. Growth of pathogens in the system is an obvious health concern. At the same time algae and bacterial slimes can also provide a site for scale formation, including elevating the pH of the water by consuming alkalinity, and inducing scale formation. A range of oxidizing and non-oxidizing biocides are normally used to prevent fouling. Typical oxidizing biocides are chlorine and bromine. Non-oxidizing biocides include a wide range of organic compounds each with unique bio-cidal activities. Many biocides are proprietary mixtures aimed at specific applications and are formulated to avoid interference with other chemicals used in the systems.

TREATMENT TECHNOLOGIES STUDIED

Programmable Controller

All of the cooling towers in this study were being controlled by flow proportional controllers that were set to open the bleed valve for a specified period of time (usually around 3 minutes) for every 50-60 gallons in inflow. The flow of water through the bleed lines normally remained constant because the elevation of the water in the sump did not vary, and each line bled to an open drain, so there was no back pressure. Flow rates in the bleed lines were approximately 5-6 gpm, so the resulting ratio of feed to bleed was in the vicinity of 3.

For purposes of this study the researchers needed a more capable controller that was capable of bleeding on the basis of conductivity, could control pH levels, and was able to log flow and chemical conditions in the system. The Chemtrol controller, made by Santa Barbara controls was selected for the study. This controller was capable of all of these functions, plus it had the ability for remote reading and programming via a telephone line, which made it an ideal choice.

The Chemtrol CT3000 controller was able to log inflow of makeup water into the systems. It logged the levels of pH, conductivity, and temperature as well. Up to four chemical feeds were available in addition to feeds for acid based on the system pH.

Bleed could be controller either on the basis of the conductivity in the circulating water or as a proportion of inflow to the system. Internal modems were added to the systems operating on alkalinity control so that the pH levels could be check daily in Boulder or the office of the water treatment company.

Conventional Treatment

Conventional treatment of evaporative condensers has four main goals: to prevent scale formation, to prevent corrosion, to prevent biological fouling and to keep the system clean of dirt and debris.

Scale control has traditionally relied on chemicals that act as inhibitors (or sequestering agents), dispersants, surface agents, and crystal modifiers. [5, 6] Inhibitors include chemicals such as polyphosphates, organophosphorous, and various polymers. All of these chemicals "delay" the formation of calcium and magnesium scale by reacting with the precipitate just as it forms. This requires a lower dose (threshold) of chemical, in the range of 1-5 mg/l (or 7.5 to 37 pounds per million gallons) since not all of the calcium or magnesium needs reaction, just the precipitating ions. Inorganic polyphosphates have traditionally been used extensively for this purpose, but sequestering agents (such as EDTA) have not been found to be practical in evaporative condensers due to the high dosage rates required. In the 1980's organic phosphonates, which are compounds of phosphoric acid, began to be used. These function similarly to the polyphosphates by delaying carbonate precipitation. Note that the emphasis in both cases is on delay of precipitation rather than prevention.

Dispersants are chemical compounds (such as polyelectrolytes) that add an electrical charge to the surface of suspended solids. These disperse the suspended solids by adsorbing onto their surfaces. The resulting similar electrical charge acts as a repulsive force, keeping the particles in solution. These chemicals are thus the opposite of coagulants, which use electrical charged chemicals to break down the repulsive forces and encourage the formation of a settable floc. [7]

---

[5] Chemtrol Instruction Manual, Santa Barbara Controls, Santa Barbara, CA

[6] Nalco Handbook, pg 21.11

[7] Nalco Handbook, pg 21.12,13

Surface agents, or surfactants are used primarily for control of biomasses (which can lead to scaling). They are frequently used in conjunction with chlorine as biocides.

Crystal modifiers including organic polymers act not to prevent scale formation, but to change the physical structure of the scale itself, making it physically weak and susceptible to standard cleaning. These chemicals seek to prevent a hard scale formation by creating a weak, powdery substance that can be removed with bleed or routine cleaning of the bottom of the tanks.

Traditional water treatment seeks to delay scale formation through one of several approaches that include: threshold inhibition, dispersion, or crystal modification. Most of the traditional chemical systems have not proven successful at high cycles of concentration using the types of water found in this test area for make-up. The resulting concentration of alkalinity and hardness tend to overwhelm the treatment, and scale formation occurs. This has led to design of advanced chemical systems, and manufacturers have sought to duplicate the chemical processes using physical systems. The systems tested in this study include one advance chemical system and two physical systems.

Physical Systems

Electro Static

Just as chemical agents, such as polyelectrolytes, seek to disperse the microscopic scale particles, and keep them from coalescing into solid scale deposits many companies have sought to use physical forces to accomplish the same purpose. Such a system is the Zeta Rod™ , which is manufactured by the Zeta Corporation of Tucson, AZ. The Zeta Rod system is advertised in the company literature as a "replacement"[8] for chemical treatment in cooling systems. The rod itself is a "durable ceramic electrode capable of holding a charge many times greater than previously possible."[9]

The Zeta Rod injects a 35,000 volt DC[10] electrical charge into the circulating water system in order to create a mutual electric charge on the precipitation particles.

---

[8] Zeta Manual, Appendix B, page 3

[9] The Zeta Story, pg 2.

[10] Ibid, pg 2

The charge rod is claimed to form a capacitor involving the circulating solids and the walls of the tank. This capacitance is the purported mechanism by which like charges are created on the colloidal particles. With a Zeta Rod in place the cooling systems are instructed to be operated at from 5 to 8 cycles of concentration[11], with pH's of 8.9 to 9.1, which is well above the carbonate inflection point of 8.3. In these ranges the water should highly scale forming, but the manufacturer claims that any scale formed should fall to the bottom of the tank. The scale particles are designed to remain in "stable dispersion by the Zeta Rod preventing them from adhering onto surfaces, and the colloidal precipitates are continuously eliminated in the reduced bleed." [12]

The manufacturer's literature clearly states that the intention of the Zeta Rod is to control scale and biofilm without the need for *any chemical additions* and with the systems operating a 5-8 cycles of concentration with pH's between 8.9 and 9.1. As such, they were an ideal candidate for this study, because our goals were to run the evaporative coolers at approximately 6 cycles of concentration, using whatever set of operating instructions the manufacturer provided. The researchers were also quite interested to test system that did not require chemicals.

Aquacraft initially contacted the Zeta Corporation in October, 2001 to solicit their participation in the study. The researchers provided them with chemical reports on the water at two stores and hoped to use their system at: USC and Sun City. The company agreed to participate in a no-cost demonstration of their technology. They agreed to provide and install the equipment on the two stores so it could be operated for at least three months at cycles of concentration of 6. In October of 2002 Mel Hector for Zeta Corporation came to Los Angeles and installed the units on the two stores. The chemical additions were stopped and the conductivity controllers, used to regulate bleed were reset in order to increase the cycles of concentration to between 5 and 6. The systems began operation on October 8th, 2002.

---

[11] Ibid, page 5

[12] Ibid, page 6

Electro Magnetic

A second category of physical treatment approaches is based on the use of electro-magnetic radiation to induce electrical fields in the flowing water solution. These fields modify the crystalline structure of the scale minerals. In this way the electro-magnetic approach is parallel to the chemical crystal modifiers, such as organic polymers.

There are several systems that use the electro-magnetic approach to water treatment, but they all rely on the same theoretical basis. This is explained in a paper by Dennis Opheim. The electro-magnetic approach relies on a oscillating electromagnetic field that is generated in a pulsing fashion and applied to the flowing fluid. Originally, these were used for pasteurization of food products, and have been approved by the FDA for this purpose.[13]

An adaptation of this technique called the Dolphin system has been used for treating cooling towers. In this application the device never comes into direct contact with the water flowing in the open loop of the cooling system, they consist of oscillating and exponential decay wave forms, and they operate at much lower power levels than in the food industry. The process is held out as being capable of controlling bacteria and scale formation in the towers. According to the paper, "under pulsed-power treatment, precipitation (of calcium carbonate) occurs in the bulk solution as a powder. These growing particles incorporate microbes and limit their growth."[14] The paper goes on to explain that pulsed-power systems induce precipitation to occur on suspended particles rather than on the walls of the pipes and tank. The particles then drop out of solution as a powder, which is flushed from the system with the bleed. Systems using this treatment can then operate under scale forming conditions without having scale for on the internal surfaces.[15] An example system is cited of a skating rink cooler, which according to the chloride levels is operating at a concentration ratio of 16.6, with inflow concentrations of calcium of 119 mg/l and alkalinities of 89 mg/l. These waters are very similar to those found in Southern California, and the report claims that, "By visual inspection, the heat

---

[13] Opheim et al, pg 1

[14] Ibid, pg 2.

[15] Ibid, pg 5

transfer tube banks had absolutely no scale, and a small quantity of white power was present in the bottom of the cooling tower water tank."[16]

This system was considered to be another ideal candidate for the study since it offered high cycles of concentration with no chemical addition. The actual product that was used for the study was the Scale Viper, manufactured by Tellco Water Technologies. According to the product literature the calcium is converted to an insoluble form as Aragonite, which is identical to Calcite ($CaCO_3$) but has a different crystalline structure. The claim is that aragonite tends to be brittle and has little polar attraction to the interior surfaces of the tubes and tank walls.[17] The literature contains some inconsistencies and confusion over exactly what mechanism is occurring, but this seems to be the central notion. (For example it claims that the system converts calcium carbonate to "insoluble" calcium bi-carbonate which is the opposite of the actual chemistry. It also claims to make this conversion without altering the hardness of the water, when in fact any precipitation of calcium carbonate should result in a reduction of the water's measurable hardness.)

The Tellco company was contacted, and Mr. Richard Tell agreed to provide two units for the test after he reviewed the chemistry of the make-up water at the Arcadia and Beverly stores. Mr. Tell supervised the installation of the Scale Viper units on October 8th. At this time the anti-scale and corrosion control chemical feeds were terminated at both stores. The only chemical addition that continued was the bromine feed at the Beverly store.

While both systems rely on the same physical properties of pulsed electro-magnetic radiation it was discovered in practice that the Telco system did not have a precisely constructed reaction chamber, but relied on a hand wound coil of co-axial cable installed on site wherever sufficient pipe water accessible. (See Figure 49). This system inevitably introduced major variability into each installation. The Dolphin system, on the other had, uses a factory built chamber that is identical in all applications. As will be seen in the results section, it might have been better to use the more sophisticated

---

[16] Ibid see table 2 of pg 5 and text above.

[17] Scale

Dolphin system for this study, since this would have eliminated the uncertainty about whether the results were due to the concept of the device or the installation.

Chemical System (Alkalinity Control)

The final water treatment approach was the least controversial since it was based on chemical additions that were more familiar to all of the water treatment companies. The alkalinity control system is based on the principal of keeping the pH levels in the system below the 8.3 carbonate inflection point. In this manner the precipitation of calcium carbonate is prevented since the predominant species of alkalinity in the system is the bi-carbonate form, which is soluble in combination with calcium. Please review Figure 35 to see how this works.

The alkalinity control systems used a mixture of 40% sulfuric acid with inorganic phosphorous and polymers for scale control, azole, and molybdenum for corrosion control and bromine for or non-oxidizing biocides for anti fouling. The acid mixture is kept in 40 gallon double walled containers, and refilled on a monthly basis from 5 gallon buckets.

The initial plan was to use alkalinity control at the Santa Monica and Irvine stores, and these were to be managed by the Tri-chem Technology[18]. In December, as will be discussed below, the Scale Viper system was removed from the Beverly store and the ChemPro Labs Company initiated alkalinity control at that store as well.[19]

In summary then, during October 2002 all six stores had been converted from conventional treatment at around 3 cycles of concentration to advanced treatment at around 6 cycles. Two stores each were set up with electro-static (Zeta Rod), electro-magnetic (Scale Viper) and chemical (alkalinity control) water treatment. The bleed rates at all stores was reduced at that time and their cycles of concentration increased to between 5.5 and 6. A monitoring program was begun as is described below.

One of the complicating factors with Alkalinity control is the fact that it relies on feeding of sulfuric acid to maintain the proper control. This is normally fed by means of a chemical pump, and it is controlled by a pH sensor on the controller. A failure of the

---

Viper, pg 2

[18] Tri-Chem Technology, Corp. 1875 W Commonwealth Ave, Unit F, Fullerton, CA 92833

[19] ChemPro Labs, Inc. 941 W 190th St., Gardena, CA 90248-4398

pump, controller or sensor could lead to serious problems with the system. If the pump fails, or the chemicals are depleted the system pH will rise quickly and the system will be very unstable. One the other hand, if the sensor or controller fails to stop the chemical addition at the proper end-point the pH could drop to dangerously low levels, and corrosion could occur.

In order to help prevent these problems the Chemtrol Controllers used at the stores with alkalinity control were equipped with modems, and telephone lines were brought to the controllers. This allowed the systems to be checked from the Aquacraft offices, or the offices of the water treatment companies, on a daily basis. A sample of the data collected in this way for the Santa Monica store is shown in Figure 38. This graph covers the period from February 3 to the 27th. It shows that during this period the pH stayed consistently between 7.5 and 7.6, which is excellent. During the same period the conductivity of the system stayed close to targeted 4500 μ mhos.

There were also a few examples of problem operations. One such involved the Santa Monica store during March of 2003. On a Friday afternoon, day 1, the chemical feed was interrupted, either due to the system running out of chemical or a pump failure. Over the weekend the pH continued to rise until it reached 8.7 on Sunday. On Monday, day 4, the problem was discovered during a routine check via the modem. The contractor was notified and immediately sent a technician out to correct the problem, which can be seen as a drop in pH back to normal levels. With only a few days of out of range operations no damage was done to the system, but if this had gone undetected for a month there would have been scale formation. This shows that in systems using alkalinity control the contractor either needs to make more frequent site visits or, better, to have a telephone connection. These can be programmed to call an alarm, which provides an automatic alert, which is even better.

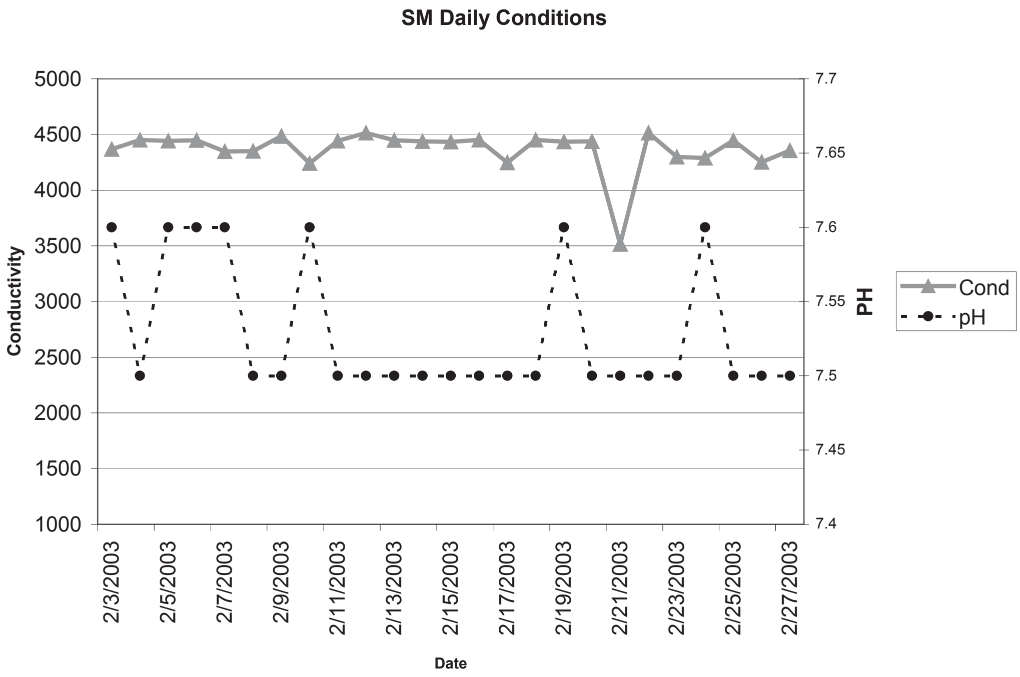


Figure 38: Daily pH and Conductivity log for Santa Monica (normal operations)

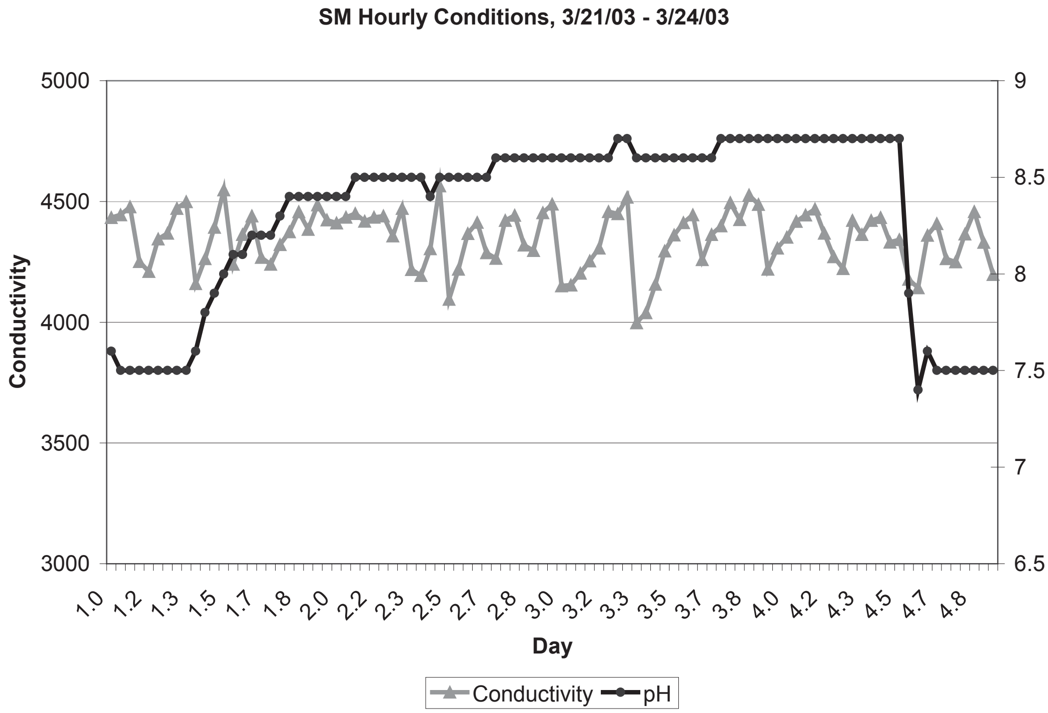


Figure 39: Operations at Santa Monica (problem operations)

RESULTS

This updated section contains results for the study sites through the end of 2003, which were made possible through the MWD grant. It also contains field data obtained for three stores in the Sacramento area at which the Dolphin system was in use. One of the goals of the extension to the study was to track the water use at the three stores for which alkalinity control was being used through the summer of 2003. This goal was largely met, but there were some complicating factors. The first was the occurrence of a labor strike, which affected operations of the stores from July through the end of the year. Also, complicating the situation were the refrigerant leak problems that occurred at both Irvine and Santa Monica in September 2003. These forced the tests to be suspended at both of these sites while repairs were made.

Arcadia

The Arcadia site was operated using the Scale Viper technology starting on October 8th, 2002. Its operations were monitored by the water treatment contractor, McMillan Water Treatment[20] and Aquacraft, Inc.

Treatment Daily Water Use

Figure 40 shows the average daily cooling use and concentration ratios for Arcadia before, during, and after the Scale Viper was in place. The cooling water use is shown by the bars, and the concentration ratios for conductivity and chlorides are shown as point values. The data for this chart are based on a relatively short periods, and the water use in September was actually lower than the long term water use as shown in Figure 41. The important fact is that while the scale viper was in place, cooling water use dropped to an average of about 1,500 gpd. Water use data were not available from 11/5/02 – 11/26/02 due to a malfunction of the data logging equipment. During this period, however, the concentration ratios based on conductivity averaged 5.7. The concentration ratio based on chlorides was over 10 for the period October 8th 2002 to November 5th 2002, but was brought down to around 6 from November 5th.to the 26th. Meanwhile the concentration

---

[20] McMillan Water Treatment, 8450 Tamarind Ave, Suite D, Fontana CA 92335

ratio based on conductivity remained around 5.5, where it was set. After the treatment was removed, water use increased to around 2,700 gpd.

Water Savings

Figure 41 compares total daily water use and cooling use before, during, and after the treatment. Both total daily water use and cooling water use decreased. Table 23 shows that cooling savings averaged at 2,135 gpd, for 59% savings. The water savings shown in Table 23 are based on the entire baseline period from April through October 2002, so they do not agree with the figures in Figure 40. Also the water savings were measured using the meter on the inflow line, which is far more reliable than the meter on the bleed line, which the researchers believe was plugged with grit during much of the pre-treatment period, and gave erroneously low bleed rate data. The water savings measured from the inflow line during this period averaged 2135 gpd and were achieved by increasing the cycles of concentration of the cooling system from approximately 2 to 6. Using the theoretical savings predicted by Figure 34 shows that as one goes from a CR of 2 to 6 the total water use by the cooling system should drop by 40%. Based on the inflow data taken just before the start of the test, shown in Figure 40, this matches quite well. The system started with a cooling use of 2500 gpd and this dropped to 1500 gpd, which is a 40% reduction.

The water savings calculated from the longer term data, shown in Figure 41 show larger savings. This implies that during the April to October period on which Figure 41 is based there must have been periods when bleed volumes were much higher and cycles of concentration much lower than those seen in the September/October period. The researchers still believe that the actual savings should be estimated using the longer period, since this reflected actual operating conditions, and will use the 2135 gpd savings shown in Table 23 for the estimate of potential savings attributable to the advanced water treatment technology.

Figure 42 shows the monthly water use at Arcadia from January 2002 to December 2003. The treatment period is highlighted, and shows the lowest water use of any two month period in the interval except for November-December 2003, which was during the strike.

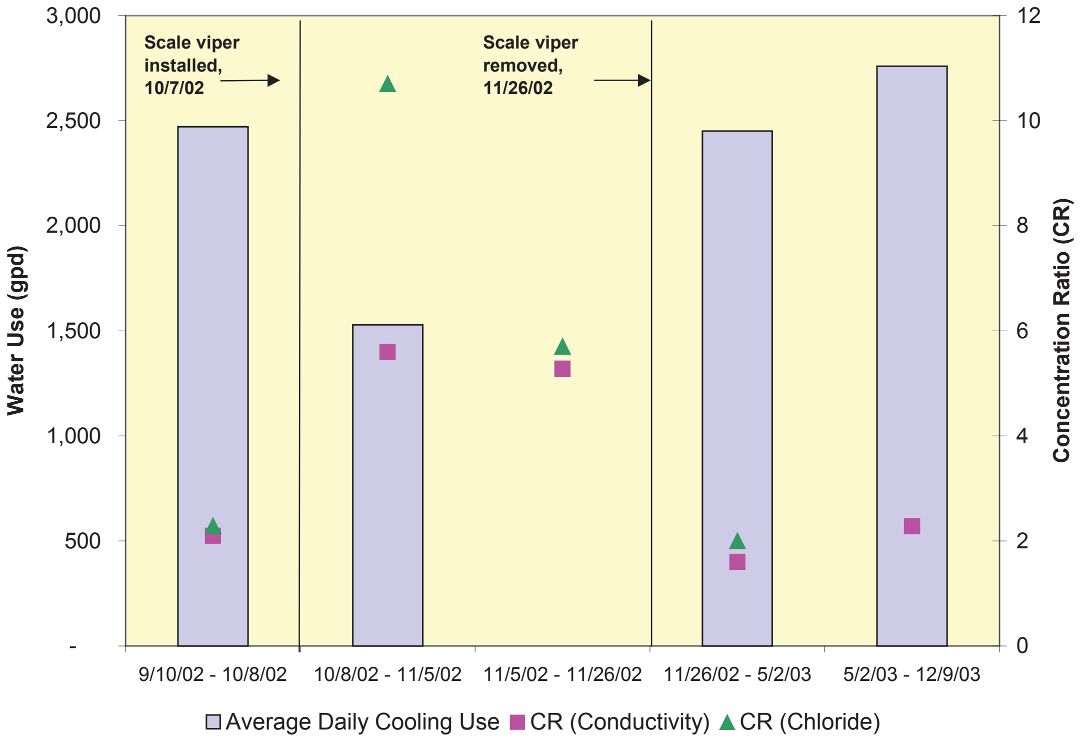


Figure 40: Arcadia's average daily cooling use and concentration ratios before, during, and after the scale viper treatment

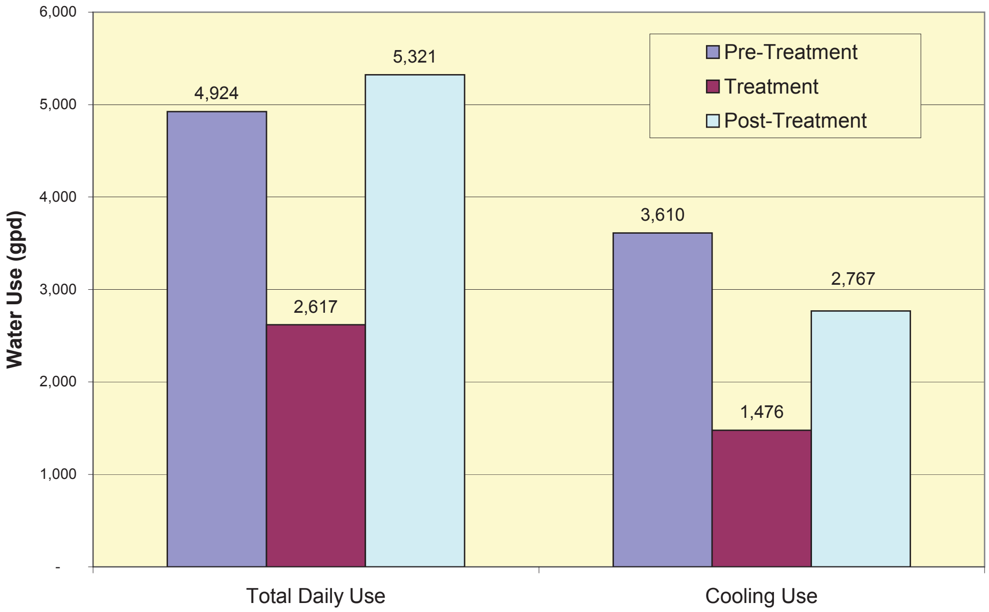


Figure 41: Comparison of total daily use and cooling use for Arcadia from the pre-treatment (4/27/02 - 10/8/02), treatment (10/8/02 – 11/26/03), and post-treatment (11/26/03 – 12/9/03).

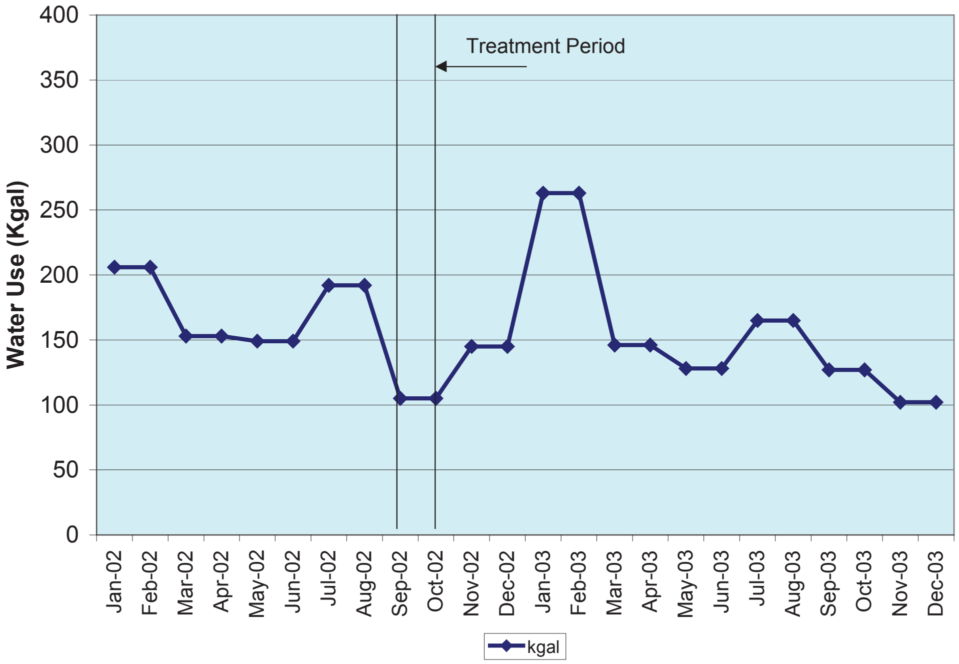


Figure 42: Water Use at Arcadia Store: 2002-2003

Table 23: Arcadia's cooling water use during pre-treatment and treatment periods

Pre-treatment (gpd)	Treatment (gpd)	Savings (gpd)	Percent Savings
3,610	1,476	2,135	59%

Scale and Corrosion Performance at Arcadia

At the beginning of the test of the Scale Viper, in October 2002, the cooling system was inspected. At that time the cooling tubes were generally free from active areas of new scale formation. There were a few patches of old scale, but the bundle was not in the process of scaling. Figure 43 shows a photo of the tubes taken on October 8, 2002.[21]

A follow-up trip to the site was made on November 5th 2002, just one month after the Scale Viper system was installed. At that time some evidence of scale formation was present, but it was decided not to take any action since conditions were not conclusive. On November 26th a second inspection trip was made and at that time the incipient scale that was observed during the previous trip had progressed to unmistakable proportions. Figure 44 was taken from the same spot as Figure 43, and one can clearly see a general coat of new scale covering the cooling tubes. Areas where old scale was found, in the lower right portion of the picture, have also begun to grow and merge in this picture.

Table 24 shows a comparison of the chemical parameters in the system at the start and end of the test. As measured by chloride, the concentration ratio in the system increased from 2.56 to 5.45 during the test, which is close to the target increase. However, during this period the calcium level in the system actually decreased, from 550 to 350 mg/l and the alkalinity levels increased only slightly. The conductivity levels increased, but not to the same degree as did the chlorides, which are considered the most reliable measure of concentration ratio, due to their high solubility. The pH levels in the system were always above the 8.3 carbonate inflection point, but decreased slightly from the start to the finish of the test. According to the Langlier saturation index (LSI) the water in the tank was consistently scale forming from start to end, but at the beginning

---

[21] In the background is Mr. Doug Potts of McMillan Water Treatment, Co.

scale formation was being inhibited with a combination of lower cycles of concentration and the anti-scaling chemicals being fed as part of the treatment; all of which were terminated during the test. An analysis of the corrosion coupons showed very little corrosion occurring during the test period.

Figure 43 Arcadia cooling system prior to treatment with Scale Viper

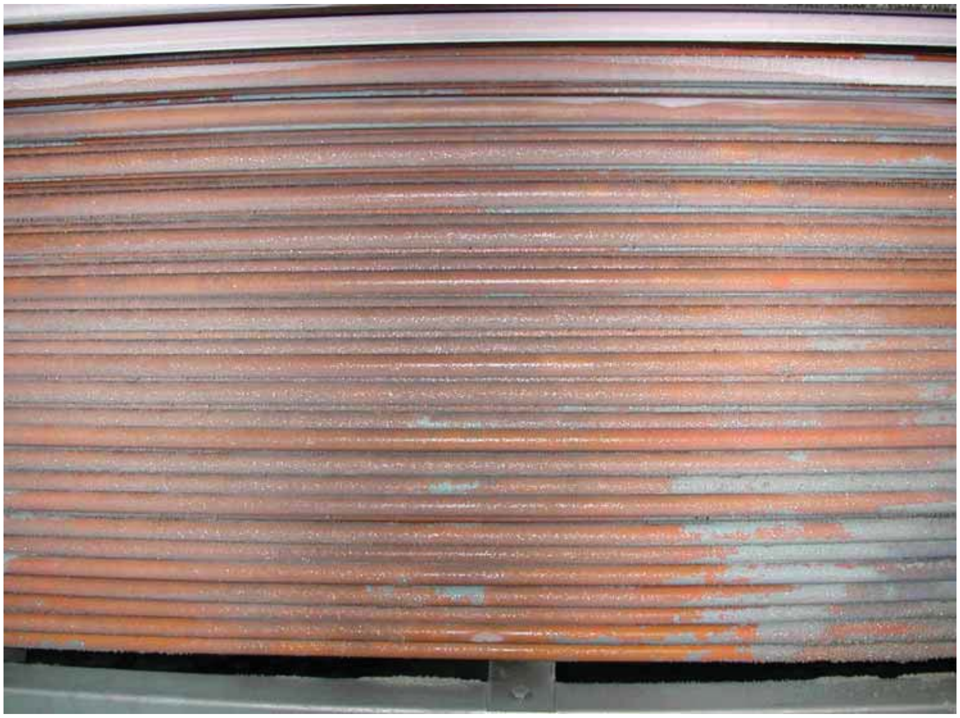


Figure 44: Arcadia tubes after 6 weeks (Nov 26, 2002)

Table 24: Chemical parameters of Arcadia tower: pre-treatment and during treatment (mg/L)

Parameter	Ave Feed Water	Tower Water 10/8/02	Tower Water 11/26/02
Calcium	150	550	350
Alkalinity	200	590	670
Conductivity	520	1200	2380
Chlorides	32	80	170
pH	7.0	8.6	8.7
LSI	-0.47	2.20	2.10
Ratios:			
Calcium		3.67	2.33
Alkalinity		2.95	3.35
Conductivity		2.31	4.58
Chlorides		2.52	5.36

Discussion of Arcadia

During this 6-week test the Scale Viper unit was installed by the manufacturer, and the cooling system was operated at cycles of concentration averaging 5.5 with no chemical additions. This complied with the instructions of the manufacturer. It appears that the system immediately began to deposit scale on the cooling pipes, and by November 26th, when the test was terminated, the scale had progressed to the point where it was impossible to tolerate. The manufacturer agreed that the test was a failure, and should be terminated to prevent damage to the cooling system. During the period that the Scale Viper was in operations, however, the water use for cooling water dropped by over 2100 gpd., which equates to over 766 kgal per year of water and wastewater.

It is interesting to consider the variation in the concentration ratios for chloride and conductivity. The system bleed was being controlled with a conductivity controller, which was set at around 2400 μ mhos. Consequently, the control system attempted to hold this level of conductivity. However, chloride cycles suggest that for a significant portion of the time the true concentration ratio may have been much higher than this, reaching levels over 10. If calcium carbonate scale is forming, that molecule will have a neutral charge and will not contribute to conductivity. Thus in a scaling system the conductivity may appear to be falling as the scale leaves solution, which is what may have been happening at this site. This means that use of conductivity control in a system that is actually allowing scale to form, but modify its crystalline structure may lead to excessive cycles of concentration caused by the loss of conductivity ions to non-ionic precipitate. In these systems it would be more appropriate to control bleed using proportional control, which uses the ratio of bleed to feed to control the system, which is not affected by changes in the ionic make-up of the water.

Subsequent to the termination of the test the manufacturer informed us that the problem with the system may have been faulty installation rather than a fundamental flaw in the operating principle. They offered the opinion that the coils had been placed too close to a bend in the pipe, and that this had prevented laminar flow conditions from occurring in the treatment area, which he felt were required for the system to operate properly. This qualification was noted, but the investigators have no opinion about its validity.

On November 26th the system was returned to standard operations. On May 2nd, when the researchers returned for anther spot check, it was discovered that the cycles of concentration were once again around 2.0 and the cooling water use had returned to approximately 2500 gpd, very similar to the conditions in October, before the start of the test.

Beverly

The Beverly site was unique in that two treatment techniques were used there. The test began with the Scale Viper system in October, and after this proved unsuccessful, alkalinity control was used. This allowed us to observe the operations under each.

Post-Retrofit Daily Water Use

Figure 45 shows the average daily cooling use and concentration ratios for Beverly from 9/6/02 to 1/22/04. While the scale viper was in place (October 8th to November 26th) the average daily cooling use dropped to less than 2,900 gpd. During this period the same discrepancy in cycles of concentration for chlorides and conductivity that the researchers saw in Arcadia was observed here. While concentration ratios based on chlorides ranged from 8.0 to 8.3 the cycles based on conductivity were only in the 5.0 to 5.4 range. It is very likely that this discrepancy is more than an artifact of variability in the chemical testing, and represents a real effect of the scale formation process. After the Scale Viper was removed from the system in late November water use increased to over 5000 gpd as the system was run lower cycles to try to de-scale the pipes. During this period the cycles were less than 2 for both chloride and conductivity and the daily water use was 5000 gpd or more. Once the alkalinity control began, water use and concentration ratios returned to levels similar to those during the Scale Viper treatment, however, there was good agreement in the cycles of concentration measured using both chlorides and conductivity. This is what one would anticipate since the alkalinity control system does not have a depressing effect on the conductivity, adding as much conductivity as it removes. Once the alkalinity control was removed, the amount of cooling use increased to about 4,200 gpd.

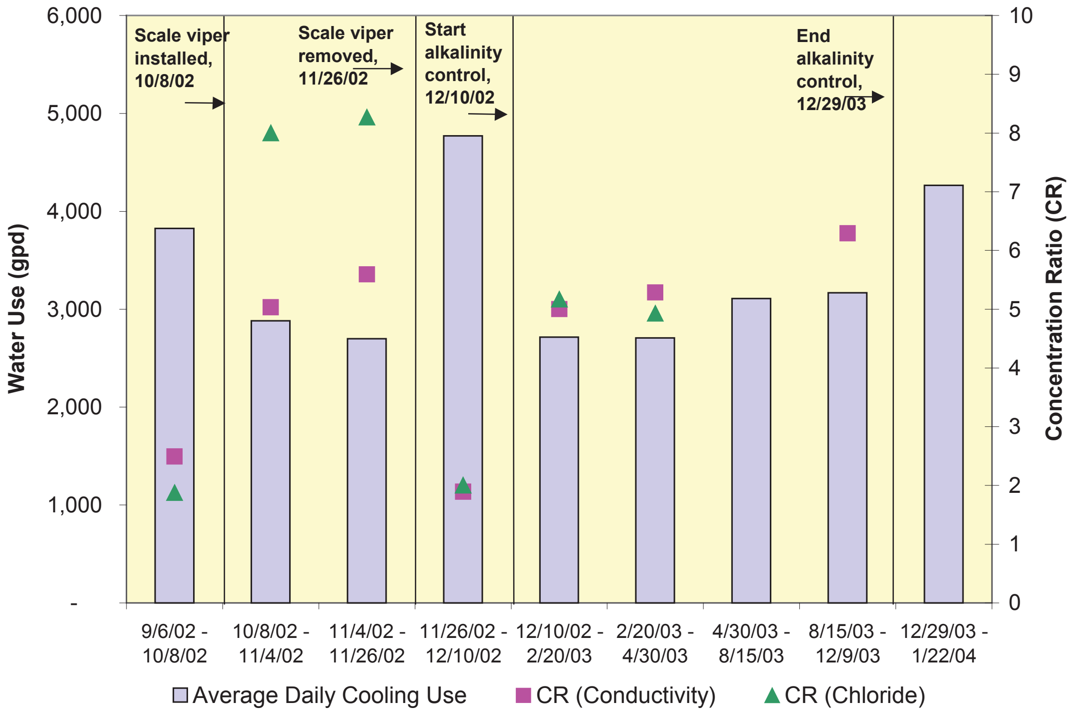


Figure 45: Beverly's average daily cooling use and concentration ratios without treatment, with a scale viper in place, with alkalinity control, and after alkalinity control ceased.

Water Savings

Figure 46 compares the total daily water use before and during the treatments, as well as cooling use before, during, and after treatments. Both total daily water use and cooling water use decreased. Total use decreased by 2,077. Table 25 shows that cooling savings averaged at 1,020 gpd, for 23% savings. It is interesting to note that there was a change in the total water use at this store of 2077 gpd compared to the change in cooling of 1020 gpd. The researchers are not sure to what this change in in-store use can be attributed, since only minor changes in faucet aerators were made in this period.

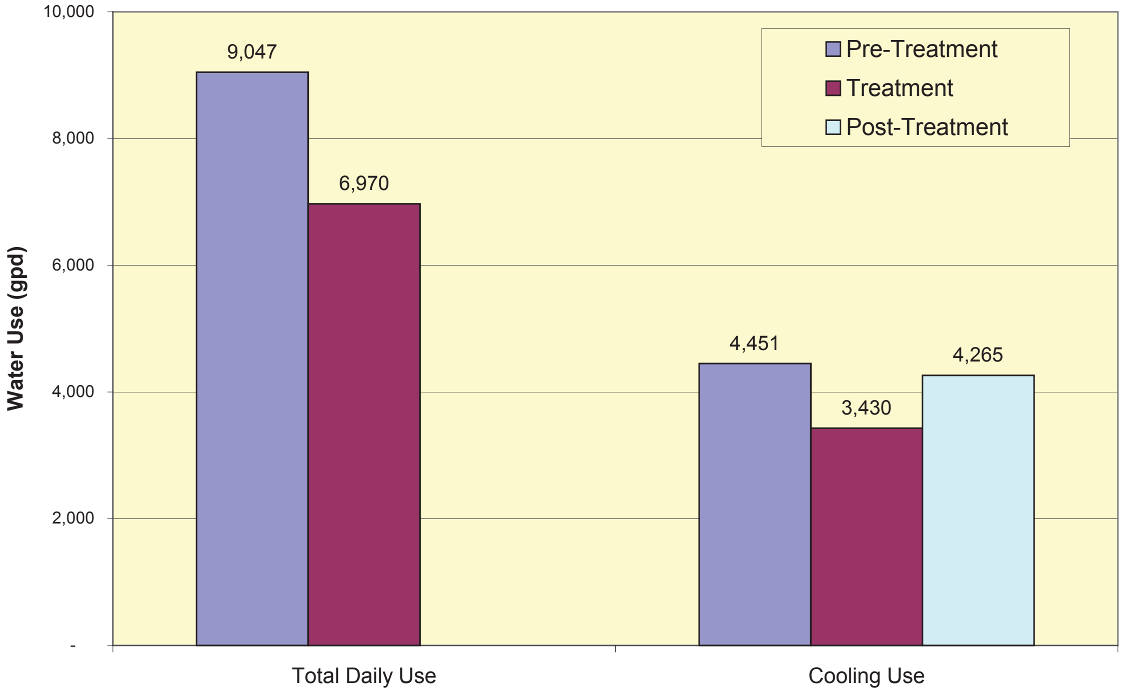


Figure 46: Comparison of total daily use and cooling use for Beverly from the pre-treatment period (4/27/02 - 10/8/02), treatment periods (10/8/02 – 11/26/02 and 12/10/02 – 12/9/03), and post-treatment period (12/29/03 – 1/22/04).

The monthly water use at the Beverly store based on billing data from LADWP is shown in Figure 47. This confirms the data shown for the baseline use period in Figure 12. The monthly use dropped from approximately 300 kgal per month prior to the start of the advanced water treatment to approximately 180 kgal per month after. This is equivalent to an annual reduction of 1.4 million gallons.

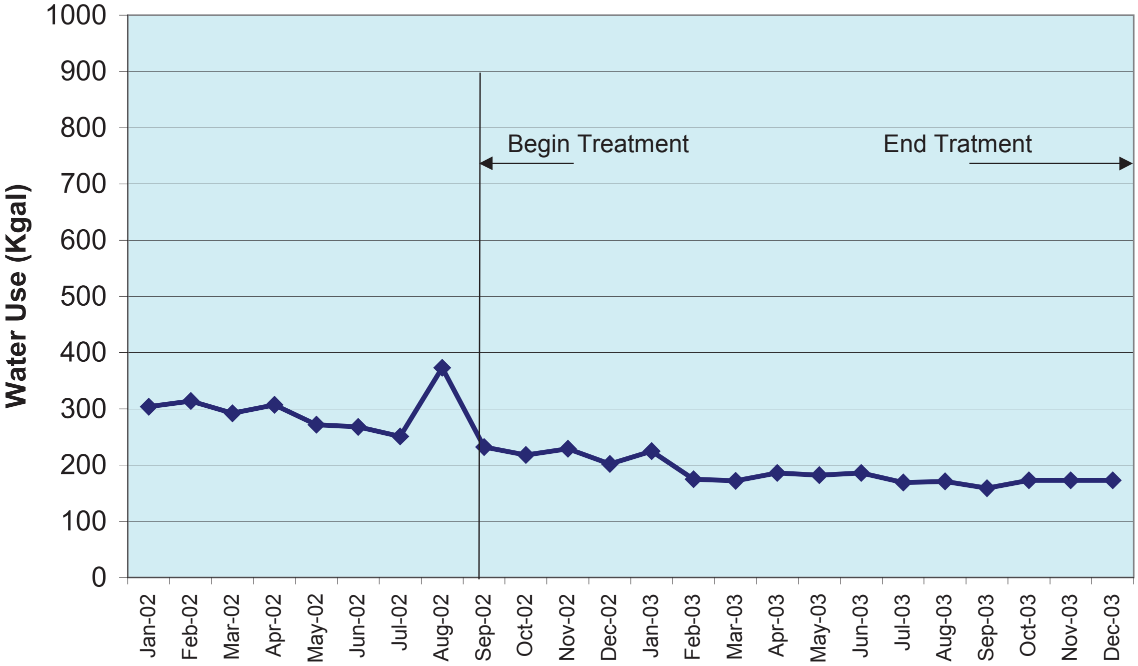


Figure 47: Monthly water use at Beverly 2002-2003

Table 25: Comparison of Beverly's cooling water use between the pre-treatment and treatment periods.

Pre-treatment (gpd)	Treatment (gpd)	Savings (gpd)	Percent Savings
4,451	3,430	1,021	23%

Since cooling water use at this store was remotely monitored via telephone modem, the change in water use could be observed as the alkalinity control treatment was discontinued. As is shown in Figure 48, in the 44 days prior to the discontinuation of treatment, water use averaged about 2,500 gpd. After the treatment ceased, water use averaged about 4,500 gpd.

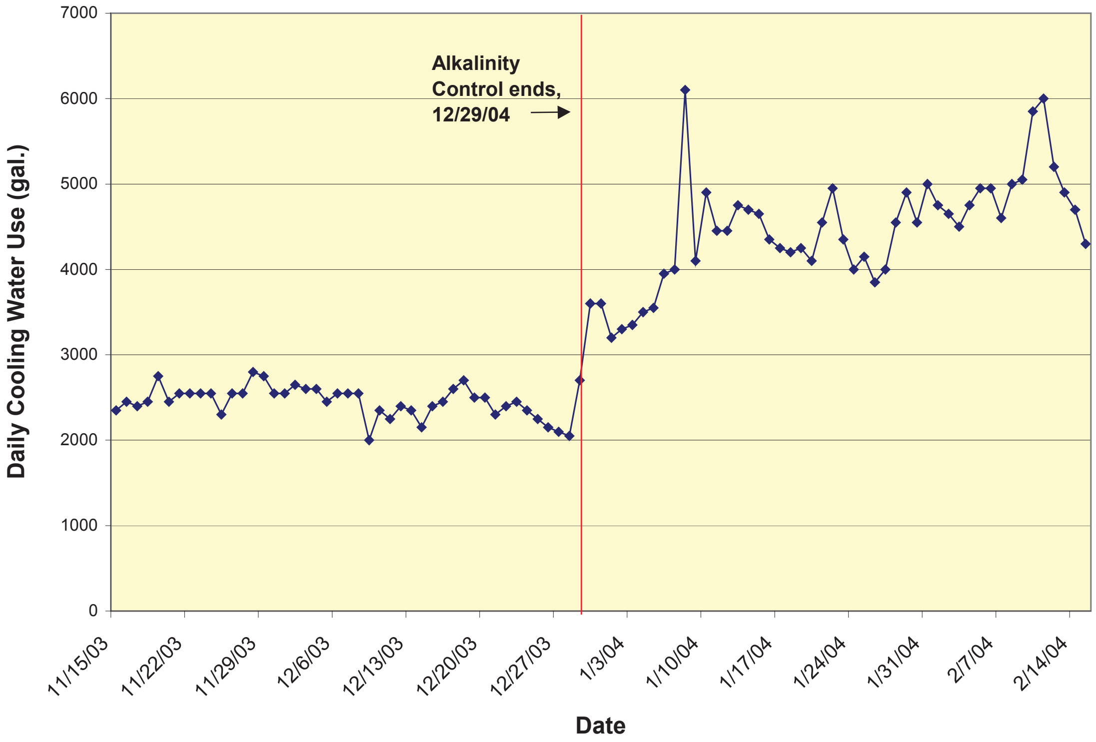


Figure 48: Daily cooling use at the Beverly store was tracked just before and after the discontinuation of alkalinity control.

Scale and Corrosion Performance at Beverly

The Scale Viper was installed on the system on October 8th, 2002. The operations of the system were immediately changed to a higher cycles of concentration and the chemical feed for scale and corrosion inhibition were discontinued. The one chemical that was left in place was the bromine feed for biological control. Figures 41 and 42 show the Scale Viper coils and control box at the Beverly store. Note that the coils, installed at the direction of the manufacturer, were adjacent to a tee in the line, which he later thought might have led to poor performance of the system due to the turbulent flow caused by the tee.

Figure 49: Scale Viper coils at Beverly

Figure 50: Scale Viper Control Box

At the start of the test the cooling tubes at the Beverly store were clear of any new scale, and the system was in general very clean, as shown in Figure 51. Even a close examination of the tubes showed no signs of scale formation. By December 10th, however, there were unmistakable signs of scale formation in the system, as shown in Figure 52. This scale was not nearly as severe as that found in the Arcadia site, but it was clearly evident that scale was forming. All of the grains that appear to be sand are in fact sites at which scale is precipitating onto the pipe. If allowed to continue, this process would accelerate and eventually the tubes would become filled with scale. Consequently, given the experience at Arcadia, the decision was made, with the concurrence of the manufacturer, to terminate the use of the Scale Viper at this site.

Figure 51: Beverly cooling tubes pre retrofit, September 8, 2002

Figure 52: Beverly tubes on December 10, 2002

In January the Beverly system was converted from Scale Viper to alkalinity control. It was run at the same approximate cycles of concentration. The chemical additions were resumed and included sulfuric acid for pH control, and a mixture of organic phosphates, molybdates and azole for corrosion protection. The system was operated continuously in this mode from January through the end of this phase of the study in May 2003. Figure 53 shows the tubes in May. They were free from any new scale, and while some of the old scale formed during the Scale Viper period was still present it was noticeably diminished.

When the chemical data were examined for this site shown in Table 26, going into the test the system was running at 2 cycles of concentration or less. During the Scale Viper portion of the test, once again the cycles of concentration measured by Chloride rise to nearly 10, while the cycles for calcium remained at 4.3 and those for conductivity rose only to 6.7. Calcium was clearly leaving solution in this system, and unfortunately at least some of it was ending up on the tubes rather than settling out in the sump, as was planned. The pH during this period stayed around 8.4, which is just over the carbonate inflection point. This may explain why the rate of scale in the system was not as high as that in the Arcadia store, in which the pH levels rose to 8.7. The addition of Bromine, a halogen, may explain the suppression of pH.

During the alkalinity control phase of the operations the alkalinity remained at 110 mg/l, which was lower than the inflow water. The pH stayed at or below 8, which is well below the point at which carbonate ions predominate. Consequently, it was chemically impossible for scale to form, and it didn’t. The cycles of concentration of the system were a bit lower than our target range of 5.5 to 6, but were acceptable. They could probably have been increased. Overall, the system was operating at approximately 5.4 cycles of concentration with pH levels at 7.9. No scale formation occurred, and corrosion coupon testing showed excellent (low) copper and steel corrosion rates.

Figure 53: Beverly tubes in May, 2003

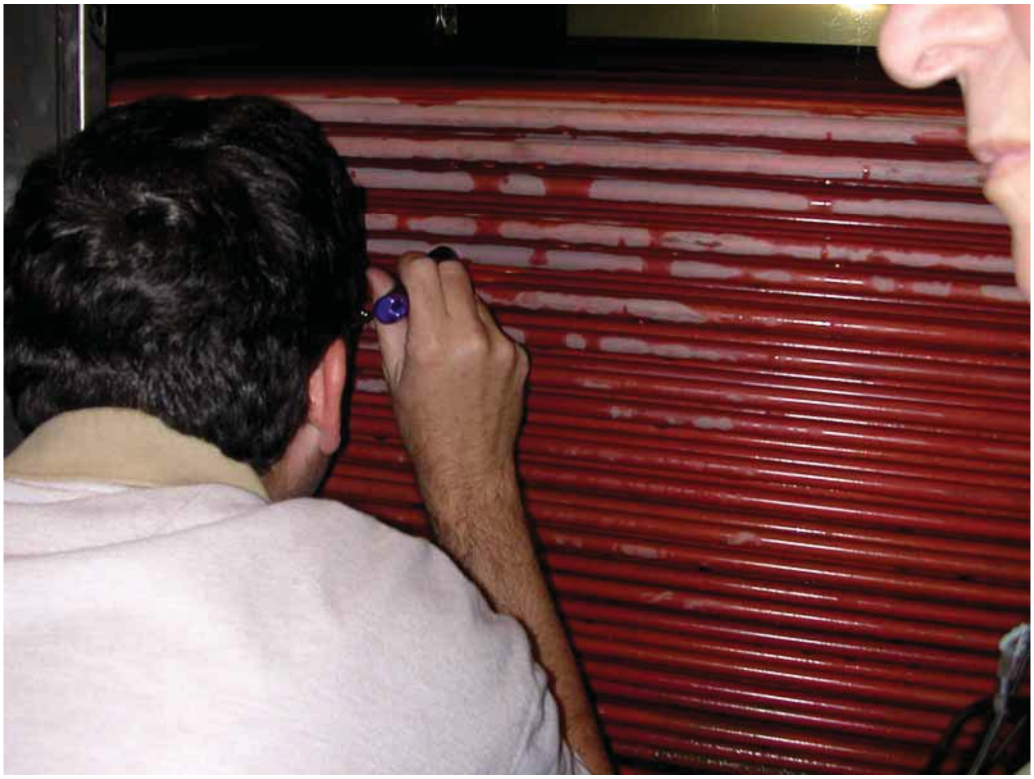


Figure 54: Mark Gentili, LADWP, inspecting Beverly tubes, May 2003

Table 26: Chemical parameters of Beverly tower pre and both post retrofits (mg/L)

Parameter	**Ave Feed Water**	**Tower Water 10/8/02**	**Tower Water 11/26/02**	**Tower Water 4/30/03**
Calcium	96	320	410	400
Alkalinity	119	384	560	110
Conductivity	506	1273	3360	2586
Chlorides	70	120	680	380
pH	7.1	8.4	8.3	7.9
LSI	-0.89	1.60	1.70	-0.45
Ratios:				
Calcium		3.35	4.29	4.19
Alkalinity		3.24	4.72	0.93
Conductivity		2.52	6.64	5.11
Chlorides		1.70	9.66	5.40

Table 27: Corrosion Coupon data from Beverly store

Metal	Start	Stop	Days	Rate (mil/yr)
Steel	10/08/02	12/26/02	49	0.70
Steel	3/4/03	4/28/03	55	1.87
Steel	4/28/03	7/8/03	71	1.63
Copper	10/08/02	12/26/02	49	0.17
Copper	3/4/03	4/28/03	55	0.03
Copper	4/28/03	7/8/03	71	0.03

Discussion of Beverly

The experience at the Beverly store was very similar to that in Arcadia with respect to the Scale Viper. During its operation the water use dropped, in this case by approximately 40%, and water savings occurred of approximately 1700 gpd, or 620 kgal per year. Unfortunately, the system developed scale problems, and the Scale Viper had to be removed.

The experience with the alkalinity control program was similar in that it decreased the amount of water used for cooling, but in this case there were no scale problems to report.

Irvine

Treatment Daily Water Use

Alkalinity control treatment was commenced at Irvine on October 10, 2002. The contractor responsible for this process was Tri-Chem Technologies of Fullerton, CA. During the next visit by the consultants, on November 7th, it was discovered that a combination of leaky bleed valve and some overflow from the tank had kept the system from reaching its desired cycles of concentration. These problems were corrected by the contractor and the system was brought up to 6+ cycles during November. Figure 56 shows the average daily cooling use and concentration ratios for Irvine just before, during, and after the treatment period. This shows that, concentration ratios ranged from 6.6 to 9.6 between November and May, and water use ranged from about 2,700 to 2,200 gpd, down from over 4000 gpd in September. During treatment between May and September 2003, the water use increased up to about 3,200 gpd. The concentration ratios were consistently higher than the target of 6.0 during treatment. After the treatment was removed, the water use increased to 3,600 gpd.

Figure 55 shows Mr. Fernando Salvador, of Tri-Chem Technologies filling the double walled chemical storage tank at Irvine. This was used to store the primary corrosion and pH control chemical, labeled CT-101. This consists of a mixture of phosphates and sulfuric acid for scale prevention and molybdates for corrosion control.

Typically, these systems consume approximately 5 gallons of chemical per month. Because the chemicals were a mixture of acids with phosphate corrosion control any increase in acid feed also resulted in an increase in phosphates. This probably explains why this system, and the similar system in Santa Monica, had problems with calcium phosphate scale.

Figure 55: Chemical storage tank at Irvine

Water Savings

Figure 57 compares total daily water use and cooling use at the Irvine store before, during, and after treatment. Both total daily water use and cooling water use decreased during treatment. Table 28 shows that cooling savings averaged at 1,047 gpd, for 27% savings while total use decreased by 1,938 gpd. After the alkalinity control was removed from the system in September, 2003 the water use rebounded from 2820 gpd to 3636 gpd, which was nearly as great as the pre treatment consumption. For some unexplained reason the total use in the store didn't increase during the post treatment period by the same amount as did the cooling use, but we are sure that the cooling use did increase since these data were based on meter readings on the cooling system feed line.
The failure of the total store water use to rise in December may be related to the fact that of the supermarket strike reducing the level of business during this period.

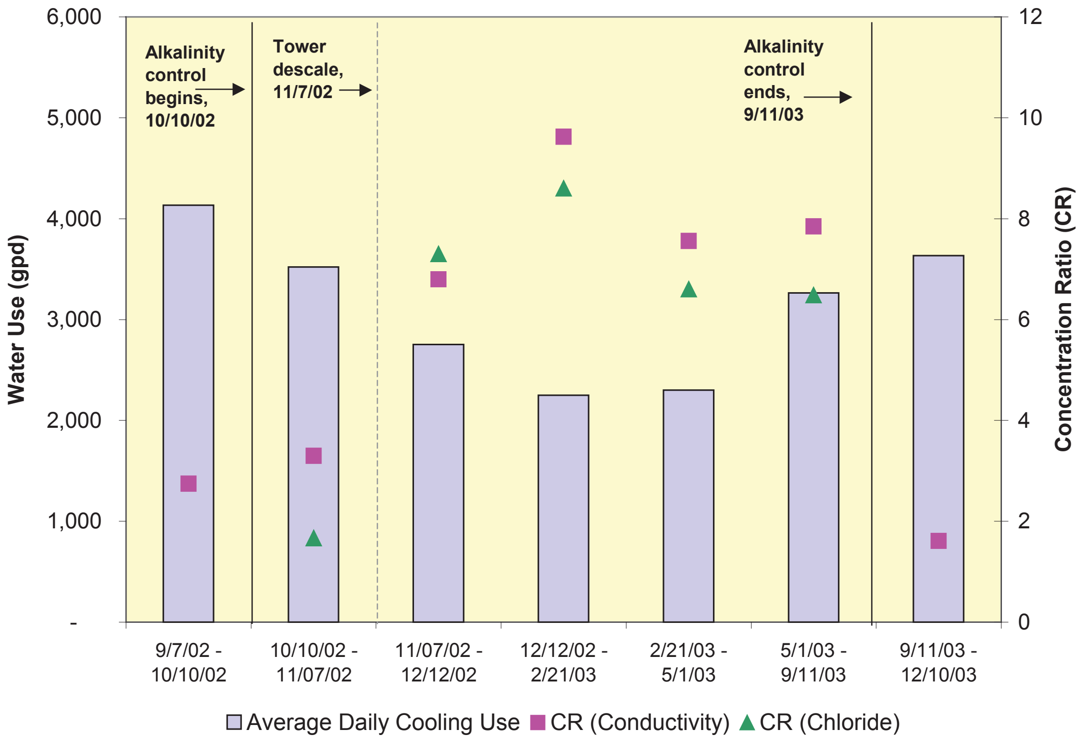


Figure 56: Irvine's average daily cooling use and concentration ratios before, during and after alkalinity control

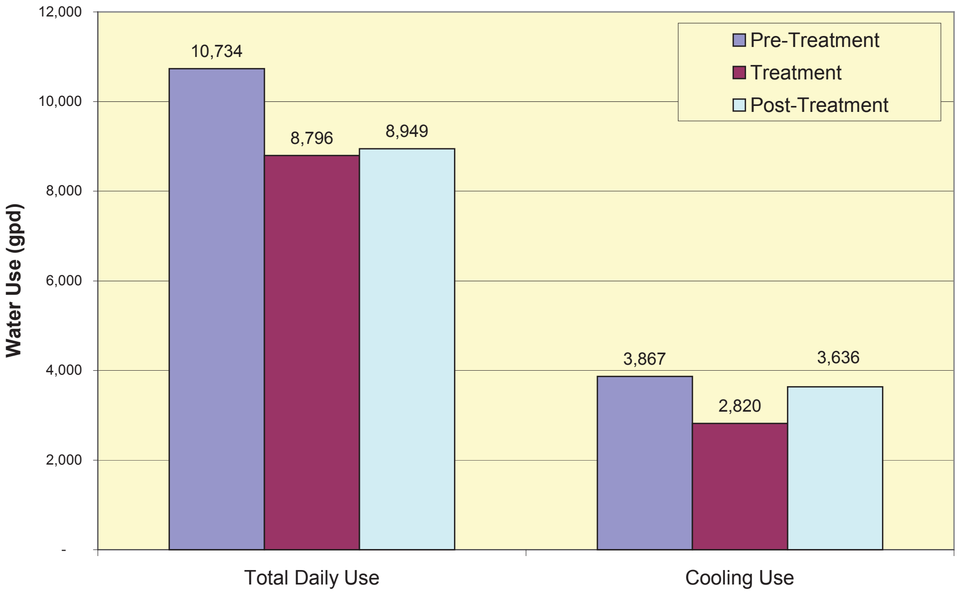


Figure 57: Compares total daily use and cooling use for Irvine from the pre-treatment (4/28/02 - 10/10/02), treatment (10/10/02 – 9/11/03), and post-treatment (9/11/03 – 12/10/03).

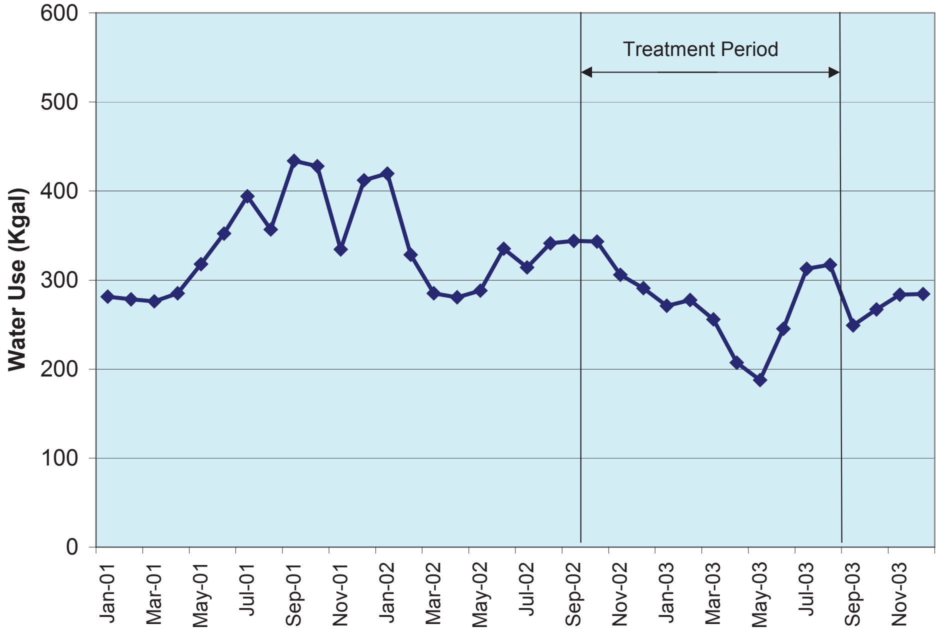


Figure 58: Monthly water use at Irvine 2001-2003

Table 28: Comparison of Irvine's cooling water use before and during treatment.

Pre-treatment (gpd)	Treatment (gpd)	Savings (gpd)	Percent Savings
3,867	2,820	1,047	27%

Scale and Corrosion Performance at Irvine

The cooling tower at Irvine was installed in 1989, so it was 13 years old at the start of the study. Figure 62 shows the condition of the cooling tubes as of November 7, 2002, before the alkalinity control program was effectively started. A second close-up of the tubes, Figure 63, shows considerable wear and pitting of the copper surface in October 2002 as well as several patches of old scale. Because of the presence of this scale on the tubes an acid cleaning was done by the contractor (McMillan) to provide Tri-Chem with a clean system. After the repairs and cleaning the system performed very consistently at the target levels of pH and cycles of concentration. When the researchers visited the site in May of 2003 it was found to be clear of carbonate scale, but the tubes were covered with a soft white film that the contractor believed to be due a variation in the anti-corrosion chemicals. This can be seen in Figure 64, which shows the tubes covered with film, and also areas where they had been wiped clean by hand. Chlorine bleach may have been used by Tri-Chem in an attempt to clean the tubes.

Table 29 shows a comparison of the chemical parameters in the feed and tower water before and after the retrofit to alkalinity control. In September the researchers saw that the tower water calcium and alkalinity levels were high, 230 and 440 mg/l respectively. This was combined with a pH at 8.7, which resulted in mildly scale forming conditions as shown by the LSI of 1.90. Under these conditions the tower would be expected to gradually build-up scale on the internal piping. This process was confirmed by the visual inspection that showed significant patches of old scale in the system, some of which can be seen in Figure 62 and Figure 63.

After the start of alkalinity control program the situation was quite different. While the calcium levels in the tower water increased to 540 mg/l, the alkalinity of 120 mg/l was less than the inflow water, and the pH was at 7.0. This resulted in a slightly aggressive water with an LSI of –0.1. The fact that the calcium levels in the tower water were elevated, is an indicator that during this period scale was going into solution (gradually) and becoming ionic in solution, which also added to the conductivity of the water. During this period, also, the chloride concentration ratio was 4.92 while the concentration ratio based on conductivity was 7.29. Which provides further evidence of a descaling process as the non-ionic calcium carbonate is liberated as calcium bicarbonate ions. This is just the opposite what the researchers saw in the stores that were scaling, such as the Arcadia store during the October-November test of the Scale Viper. In these cases the calcium ratios were lower than those of chloride as calcium left solution in the form of solid scale.

Corrosion coupons were installed on the tower at the start of the alkalinity control program, in October 2002. These were removed for testing on January 24, 2003, and new coupons were installed, which were subsequently replaced on May 16th. The results of these tests are shown in Table 30. With the exception of the steel coupon during the October to January period, which rated fair, all other corrosion rates were in the excellent range. These coupons were installed in coupon racks that were continuously circulating over the entire period they were present. Thus they integrate the corrosion over the period in which they are installed. If an isolated event occurred, such as an overfeeding of acid, this would have been reflected in an increased corrosion rate measured by the coupon. The fact that these coupons were all in acceptable limits indicates that the system operated in a stable manner for the whole test period.

It is not necessary to rely totally on the data from the coupon racks to assess the operation of this system. Hourly data on pH and conductivity were recorded by the programmable controller and downloaded. These have been plotted in Figure 59 through Figure 61. These figures provide a continuous record of the pH and conductivity, except for a period from November 2002 to January 2003. During the period of record the data show that pH levels stayed consistently around 7.5 to 8.0. There was a brief period of a few hours where the pH dropped to between 3 and 4, as shown in Figure 61. This drop in pH was confined to just the sensor by-pass line, and coincided with the repair of a leak in one of the tubes which required the water to be turned off. When the water stopped circulating in the sensor by-pass tube the pH dropped as a small amount of acid in the feed line entered the tube. The pH in the main tank was unaffected.

Table 29: Chemical parameters at Irvine pre and during treatment (mg/L)

Parameter	Ave Feed Water	Tower Water 9/7/02	Tower Water 5/1/03
Calcium	57	230	540
Alkalinity	183	440	120
Conductivity	465	1055	3390
Chlorides	33	na	160
pH	8.1	8.7	7.0
LSI	0.25	1.90	-0.10
Ratios:			
Calcium		4.06	9.53
Alkalinity		2.40	0.66
Conductivity		2.27	7.29
Chlorides		na	4.92

Table 30: Corrosion rates at Irvine: October 2002 to May 2003

Metal	Start	Stop	Days	Rate (mil/yr)
Steel	10/10/02	1/24/03	106	3.97
Steel	1/24/03	5/16/03	112	0.07
Copper	10/10/02	1/24/03	106	0.18
Copper	1/24/03	5/16/03	112	0.02

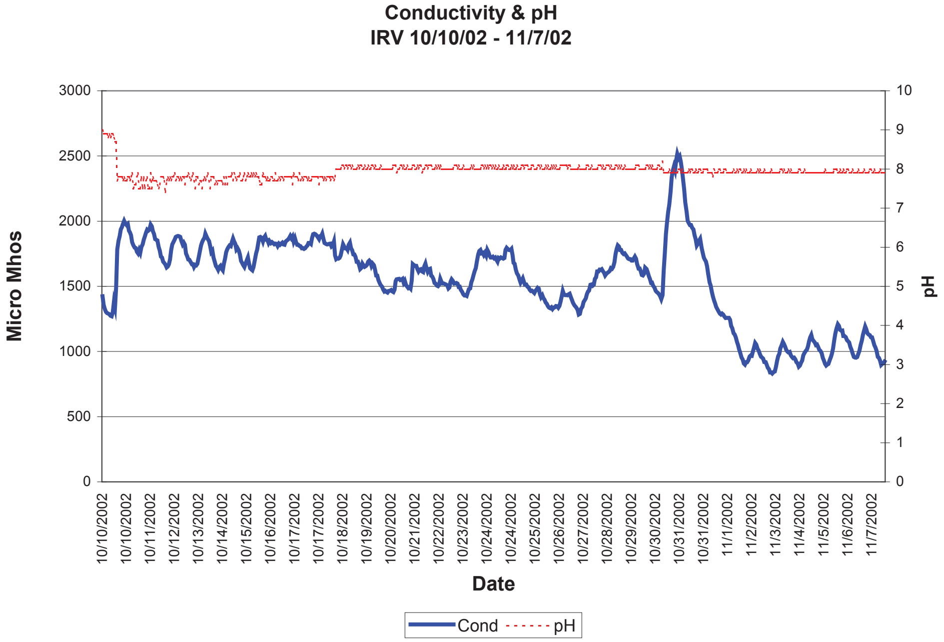
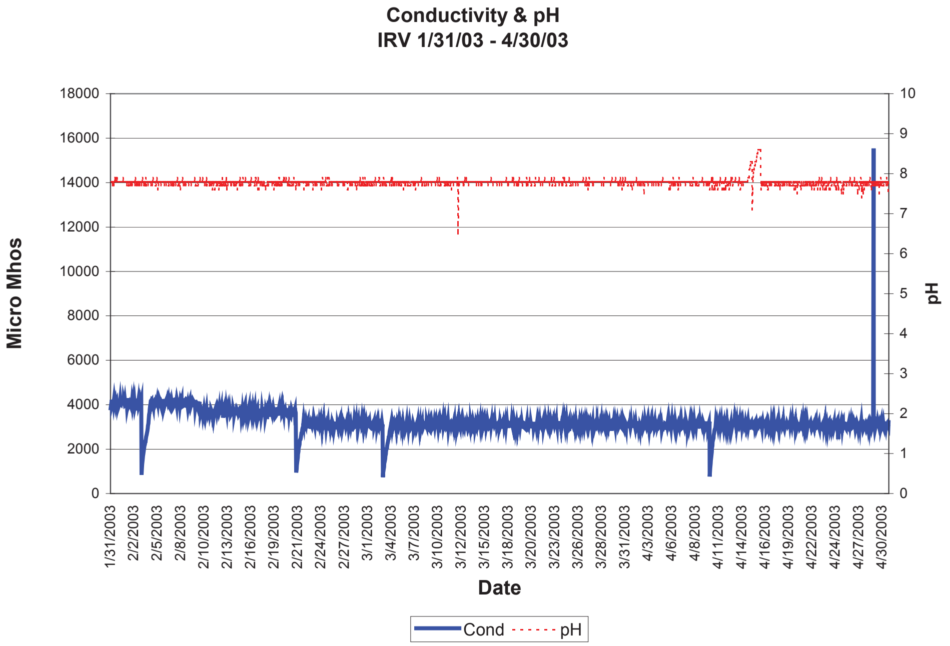


Figure 59: pH and Conductivity at Irvine: Oct.-Nov. 2002



Conductivity & pH
IRV 1/31/03 - 4/30/03

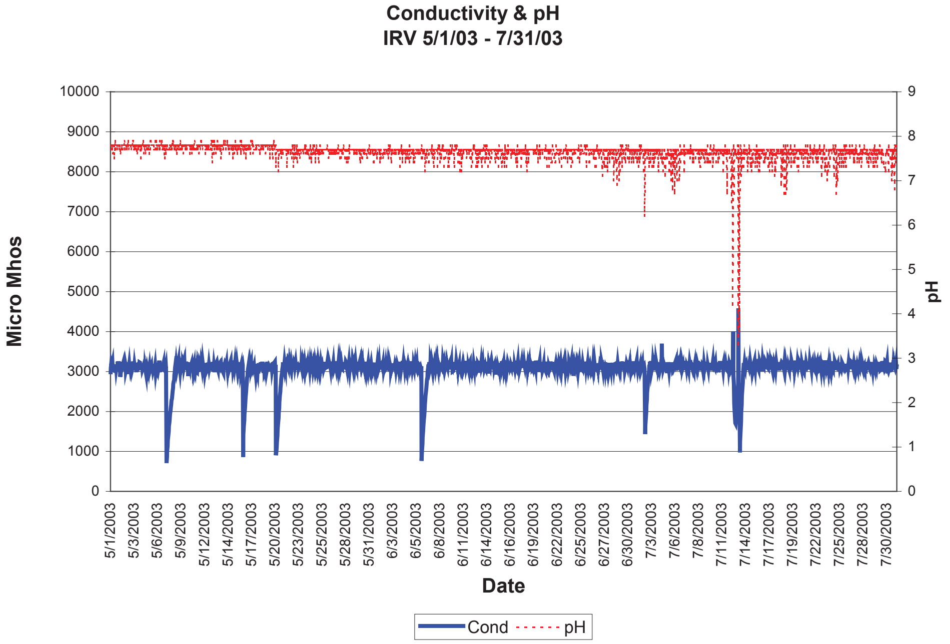


Figure 61: pH and Conductivity at Irvine: May-July 2003

Figure 62: Top view of Irvine tubes on Nov 7, 2002

Figure 63: Irvine pipes side-view close-up, October 2002

Figure 64: Irvine cooling tubes in May, 2003

Discussion of Irvine Operations

The operations at the Irvine store after the start of the alkalinity control program were uneventful. The system was operated at 6 or more cycles of concentration and cooling water use dropped by an average of 1047 gpd. On July 16th, 2003, however, the system developed a leak in one of the cooling tubes. This was followed by a second leak a few days later. Naturally, the occurrence of two leaks within a short period of time, after the system had operated for over 13 years with no leaks[22] raised concerns about their cause.

The first leak was described as a complete break in the cooling pipe, approximately 8" from the bottom of the bundle near the point at which it connects to the u-tube. The metal at the break was observed to be very thin. The second leak was smaller, and was a split of about ¼" in length parallel to the central axis of the pipe. The same metal thinness was noted.

There are two basic explanations for the leaks developing in the system:

There has been a failure of the alkalinity control system, which led to high doses of acid in the system causing extremely high rates of corrosion in the copper tubing, or

These leaks are the result of wear and tear on the system during its 13-year life, and the corrosion in the copper caused by repeated routine acid washings for de-scaling. In this case the gradual de-scaling of the pipes caused by the alkalinity control may have remove scale deposits that were helping to maintain the integrity of the system.

There is no evidence to support the first theory. Both the corrosion coupons and the data from the controller show that except for a very brief period, the pH levels remained just under 8. All of the corrosion rate information from the coupons confirms this, showing excellent (low) rates for the copper. Finally, if there had been an uncontrolled infusion of acid into the system it would have resulted in a higher than normal chemical consumption for the period in which it occurred, which was not noted. At the same time a large acid infusion would also have led to the premature emptying of the chemical tank, which would have caused the pH levels to rise drastically and a massive scaling event to occur. No such situation happened. On the other hand the

---

[22] Based on information from Mr. Robert Solberg, Market Refrigeration, 8/6/03

condition of the tubes at the start of the test plus the fact that the case showed many areas of rust and corrosion, suggest that the cause is wear and tear. The tube bundle was examined at the shop of the refrigeration contractor that replaced it. A typical section of the tubes showed that on their tops the metal had eroded to the point that it was no more than foil.

Santa Monica

Santa Monica was a sister site to Irvine in that the same contractor, Tri-Chem, operated an alkalinity control program there. The alkalinity control system was installed on October 9th, 2002, it ran successfully until Sept 2003 when the system developed a leak. We do not believe that this leak was due to anything but the age and condition of the system, but since this occurred during the grocery strike, and at the end of the scheduled study the owners elected not to extend the study through the end of 2003 and terminated the alkalinity control in September. The fact that the same contractor was managing the treatment at this site and at Irvine, the other site that had leak problems, did cause some concern about the treatment procedures, and contributed to the decision not to resume the alkalinity control with that contractor.

Treatment Daily Water Use

Figure 65 shows the average daily cooling use and concentration ratios for Santa Monica just before, during, and after the treatment period. Once alkalinity control began, water use dropped from about 6,200 to about 3,000 gpd. Water levels stayed below 3,200 gpd throughout the alkalinity control period. During the treatment period concentration ratios ranged from 4.1 to 8.0. After treatment was discontinued, water use increased to about 4,100 gpd, and the conductivity decreased to about 1.3 cycles of concentration.

Water Savings

Figure 66 compares total daily water use and cooling use before, during, and after the treatment. Both total daily water use and cooling water use decreased. Table 31 shows that cooling savings averaged at 2,686 gpd, for 49% savings. These water savings, at nearly 2.7 kgal per day, were among the largest in the study.

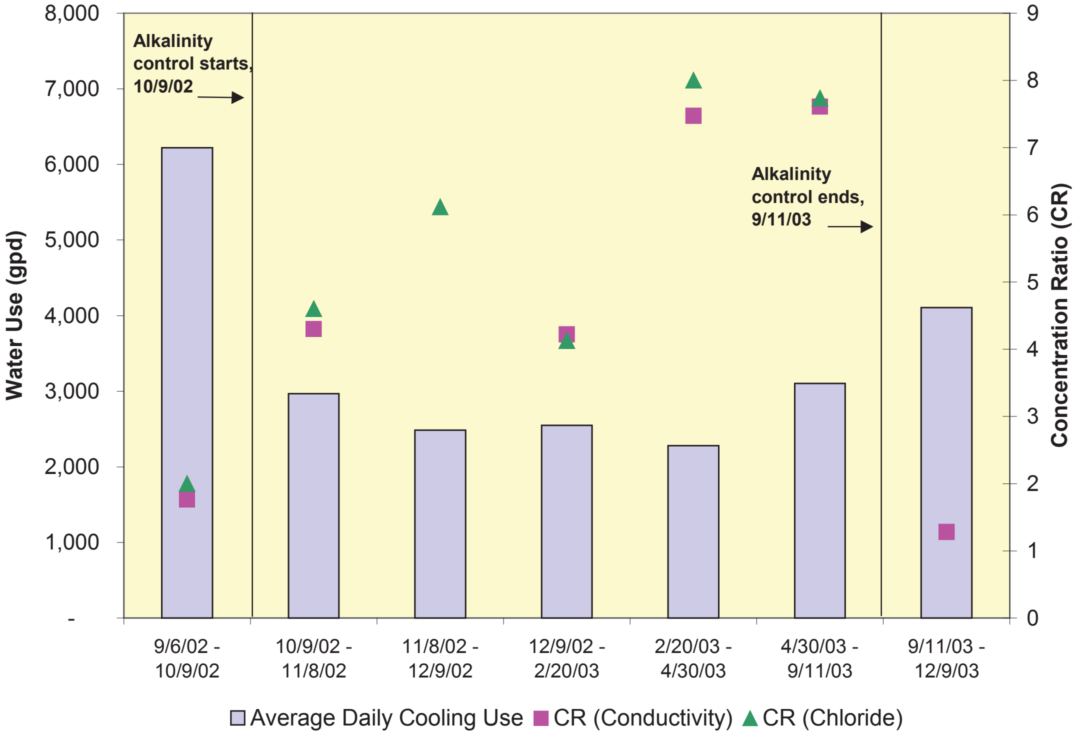


Figure 65: Santa Monica's average daily cooling use and concentration ratios before, during, and after alkalinity control.

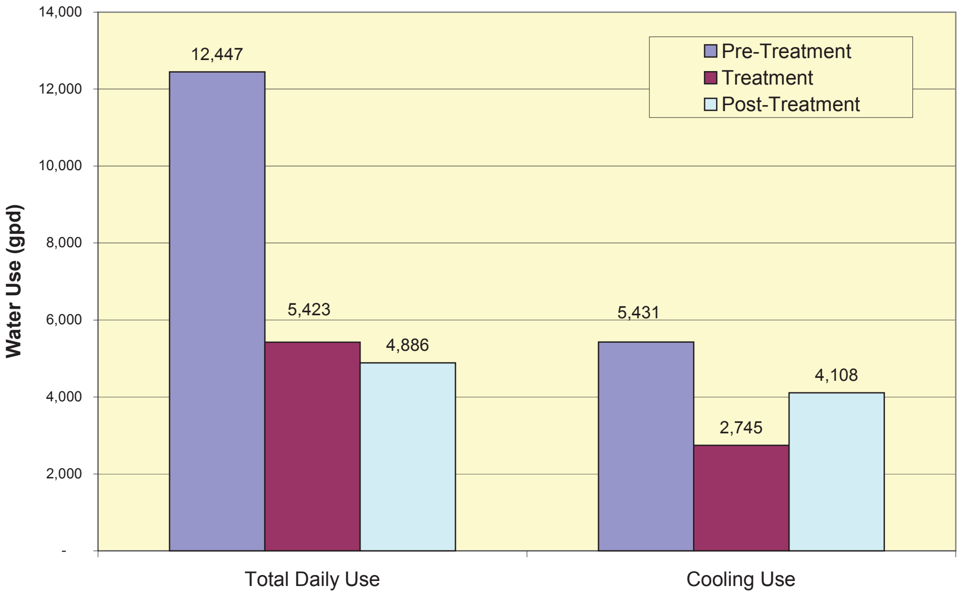


Figure 66: Total daily use and cooling use for Santa Monica from the pre-treatment (4/28/02 - 10/7/02), treatment (10/9/02 – 9/11/03), and post-treatment (9/11/03 – 12/9/03).

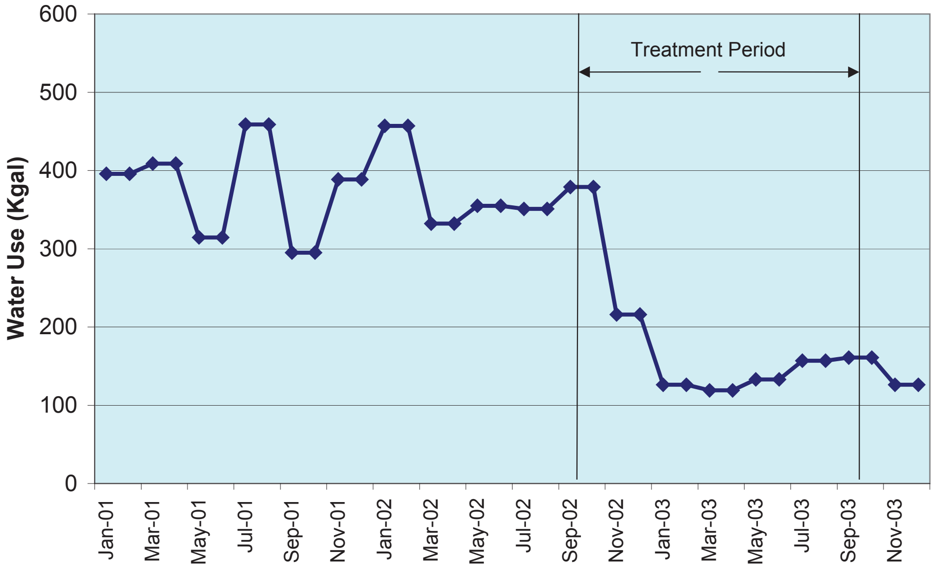


Figure 67: Monthly water use at Santa Monica 2001-2003

Table 31: Comparison of Santa Monica cooling water use between the pre-treatment and treatment period.

Pre-treatment (gpd)	Treatment (gpd)	Savings (gpd)	Percent Savings
5,431	2,745	2,686	49%

As with the Beverly store, the cooling water use here was remotely monitored so the change in water use could be observed right when the alkalinity control treatment was discontinued. As is shown in Figure 68, in the 41 days prior to the discontinuation of treatment, water use mostly stayed between 3,000 and 3,500 gpd. After the treatment ceased, water use was generally between 4,000 and 4,500 gpd, an increase of approximately 1200 gpd. The post treatment water use is thought to have been affected by the strike so the increase in use was not as large as the initial reduction at the start of treatment.

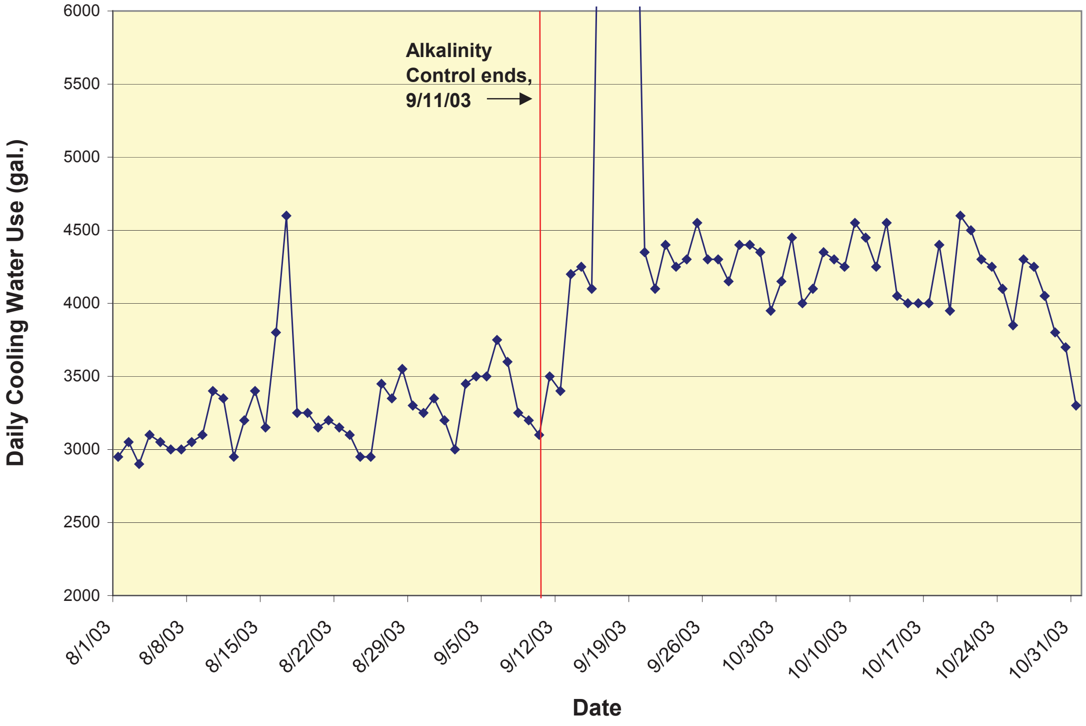


Figure 68: Daily cooling use at the Santa Monica store was tracked just before and after the discontinuation of alkalinity control.

Scale and Corrosion Performance at Santa Monica

The chemical parameters listed in Table 32 show that prior to the retrofit the cooling system was being operated at very low cycles of concentration, with chlorides at 1.87 and conductivity cycles at 1.70. During the alkalinity control program test period the cycles for chlorides rose to 8.43 and those for conductivity rose to 6.03. This was a dramatic increase that explains the reduction in cooling water use.

This system suffered a set-back when the chemical feed pump failed sometime soon after it was refilled on November 8th 2002. This occurred before the telephone modem was installed so it went undiscovered until December 6th. The data were collected by the programmable controller, were downloaded during a visit on December 9th, and are shown in Figure 69. This shows an abrupt rise in the pH from 7.8 to 8.9 on November 9th. The pH stayed at this level until December 6th when the problem was discovered by Tri-Chem. At that point they corrected the problem and the pH dropped back to the 7.8 level. The resulting rise in the pH led to some scale formation, but because the amount was small the only action taken was to drop the pH to 7.5 in order to effect a gradual de-scaling of the system.

Inspection of the cooling tower at the start of the test in October 2002 showed fairly clean tubes. Patches of old scale occurred throughout, but were seen mainly at the bottom of the bundle. This can be seen in Figure 72 and Figure 73. Clearly, this system had had scale accumulations in the past and had been cleaned leaving the patches behind. In May 2003, after 7 months of operation under the alkalinity control program visual inspection revealed no new scale. There were still some residual patches of old scale and traces of the scale that had formed during the November failure, but in general the system was clean.

Table 33 shows the corrosion rate data obtained from the coupon testing. The two sets of coupons tested at this store both showed good rates for the steel coupons and excellent rates for the copper. The coupons were in place for the entire period from October to May 16th.

The data traces for the period of the test with the exception of a gap between December 8th and 24th are shown in Figure 69 through Figure 71. These show that with the exception of the November-December excursion discussed above the only other problem period was the weekend excursion, also discussed above. The difference between the two events was that the second occurred after the modem was in place, and was discovered before even minor scale had an opportunity to form.

Inspection of the system in May, 2003 showed the tubes to be free from scale and in good condition. This can be seen in Figure 74. By the middle of August, however, there had been a change in the system. A thin layer of chalky scale had formed on the tubes, and it had a distinct greenish tint. This can be seen in Figure 75. It was around this time that a pin-hole leak developed in the refrigerant piping. This situation is being evaluated by the water treatment contractor to determine its cause. It is noteworthy, however, that the phosphate level in the circulating water was 35 ppm, combined with levels of calcium exceeding 1000 ppm could have caused calcium phosphate to precipitate. Levels of sulfate also need to be tested to determine whether calcium sulfate may also be precipitating. The copper coupon removed in August was free from any gross signs of corrosion, but it did have a faint, but distinct, green stain on its service.

Table 32: Chemical parameters at Santa Monica, pre and post retrofit (mg/L)

Parameter	Ave Feed Water	Tower Water 10/9/02	Tower Water 4/30/03
Calcium	128	170	1100
Alkalinity	153	210	90
Conductivity	700	1192	4221
Phosphate			35
Chlorides	85	160	720
pH	7.9	8.4	7.0
LSI	0.26	1.00	0.10
Ratios:			
Calcium		1.33	8.63
Alkalinity		1.37	0.59
Conductivity		1.70	6.03
Chlorides		1.87	8.43

Table 33: Corrosion coupon data for Santa Monica

Metal	Start	Stop	Days	Rate (mil/yr)
Steel	10/10/02	1/24/03	106	2.07
Steel	1/24/03	5/16/03	112	1.37
Copper	10/10/02	1/24/03	106	0.19
Copper	1/24/03	5/16/03	112	0.02

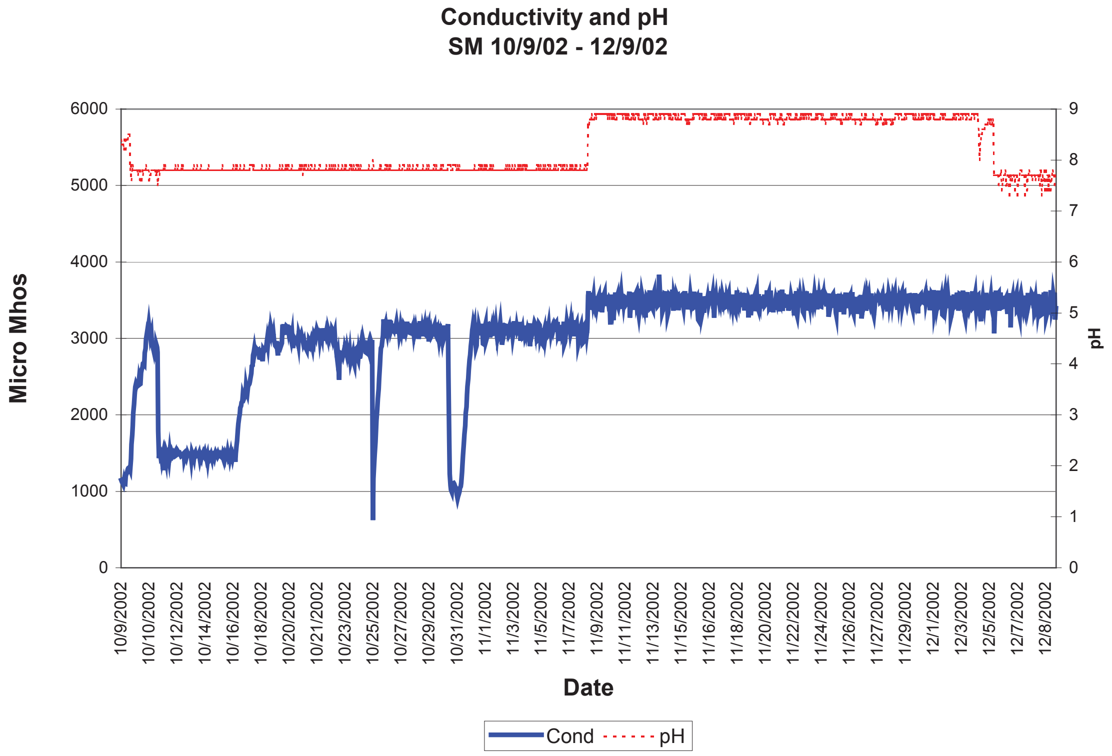


Figure 69: pH and Conductivity at Santa Monica, Oct-Dec 2002

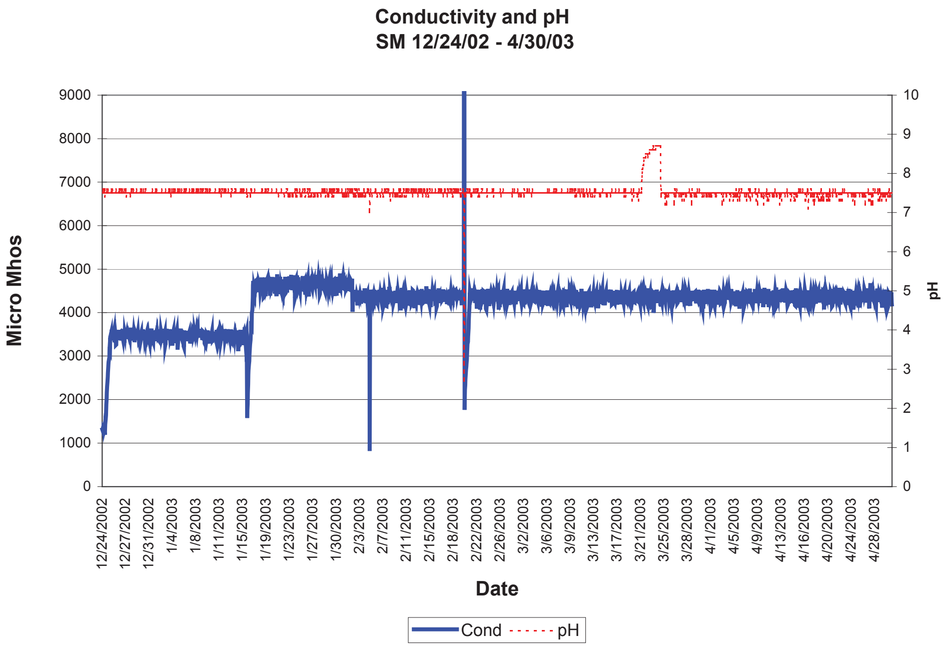


Figure 70: pH and Conductivity data, Santa Monica, Dec 2002 to April 2003

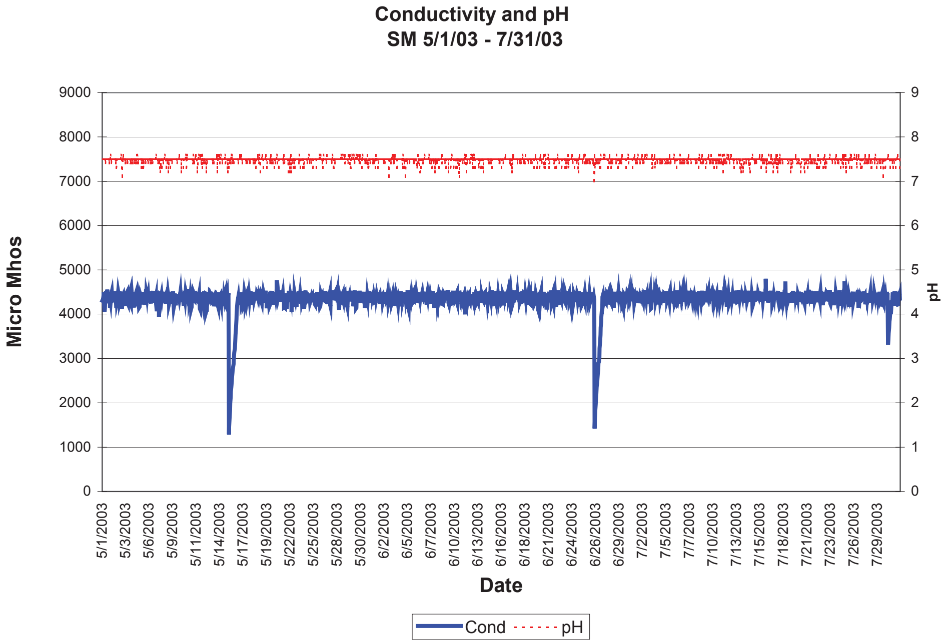


Figure 71: pH and Conductivity data for Santa Monica, May to July 2003

Figure 72: Santa Monica cooling tubes from top, Oct. 2002

Figure 73: Santa Monica cooling tubes from bottom, Oct. 2002

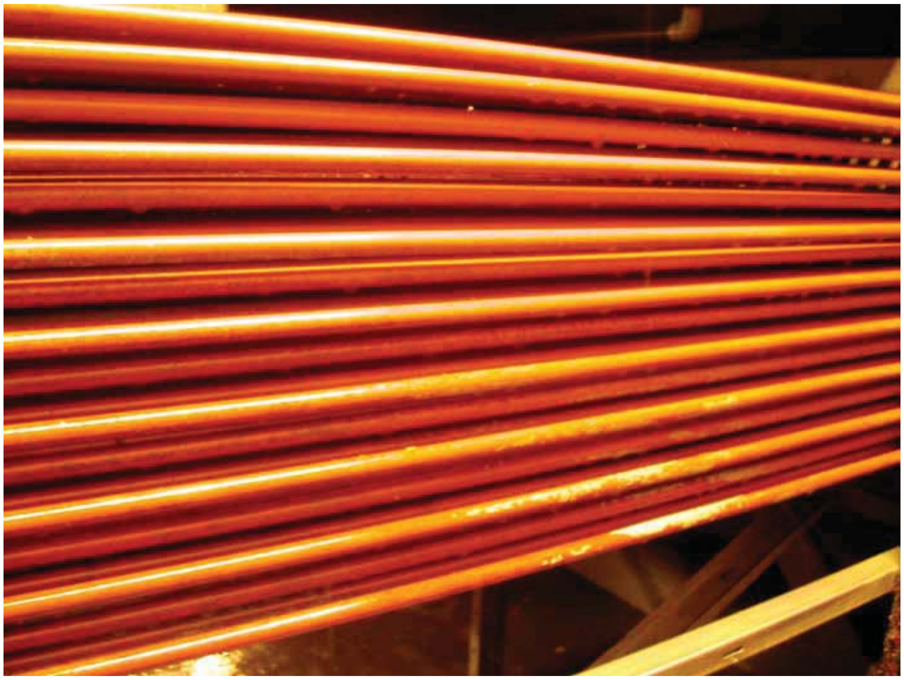


Figure 74 : Santa Monica tubes, May 2003

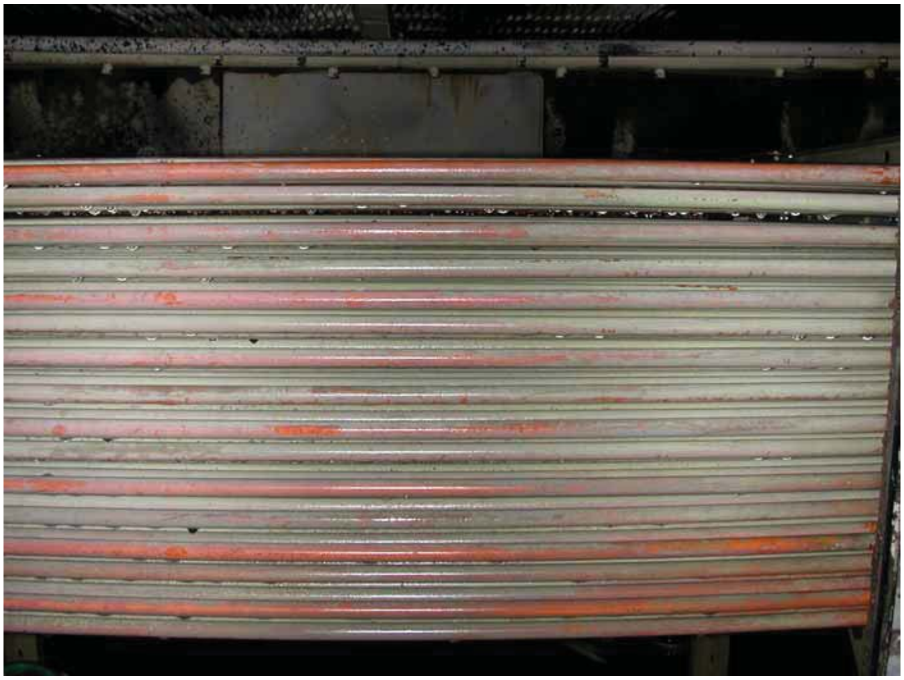


Figure 75: Santa Monica tubes, August 2003

Discussion of Santa Monica

The operation of the Santa Monica system shows the potential for this type of treatment to reduce water use in evaporative condensers and the importance of good monitoring equipment. It also shows that even with a one month interruption of chemical feed the damage to the system was slight, and no heavy cleaning of the system was required. Nonetheless, the presence of a modem link allowed the second interruption to be corrected after only 3 days, and represented a far more desirable outcome. The operating data show that except for the two periods of mechanical problems the system operated with a very steady pH. Levels of conductivity were more variable as the system was adjusted over time. Conductivity also shows dips when cleaning and bleeds occurred.

The appearance of the green tinted scale in August definitely indicates a change in the operations of the system. The greenish tint is clearly related to a copper reaction going on in the system. When sections of the pipe were sent in for analysis the scale was revealed to have high levels of phosphate and copper.

Sun City

The Sun City store was the first store used to test the Zeta Rod system. The test was begun on October 7th and was terminated December 12th, 2002 after significant new scale build up was observed. This old system was in worst shape at the start of the test of any of the stores. The enclosure was heavily corroded and there was a thin layer of glassy scale on the cooling tubes. The manufacturer, though, thought that the Zeta Rod would be able to deal with this and demonstrate its ability to de-scale old systems like this. The condition of the system at the start of the test in October 2002 is shown in Figure 78.

Treatment Daily Water Use

While the system was in place the water use was reduced significantly. Figure 76 shows the average daily cooling use and concentration ratios for Sun City while the zeta rod was in place, as well as just before and after. Once the zeta rod was installed, water use dropped from about 3,000 to about 1,600 gpd. While the rod was in place, water use ranged from about 600 to almost 1,700 gpd and concentration ratios ranged from about 4.8 to 5.8. When the rod was removed, water use was about 1,300 gpd. Sometime after May of 2003 the feed meter recording cooling water use was removed, so no other readings were possible.

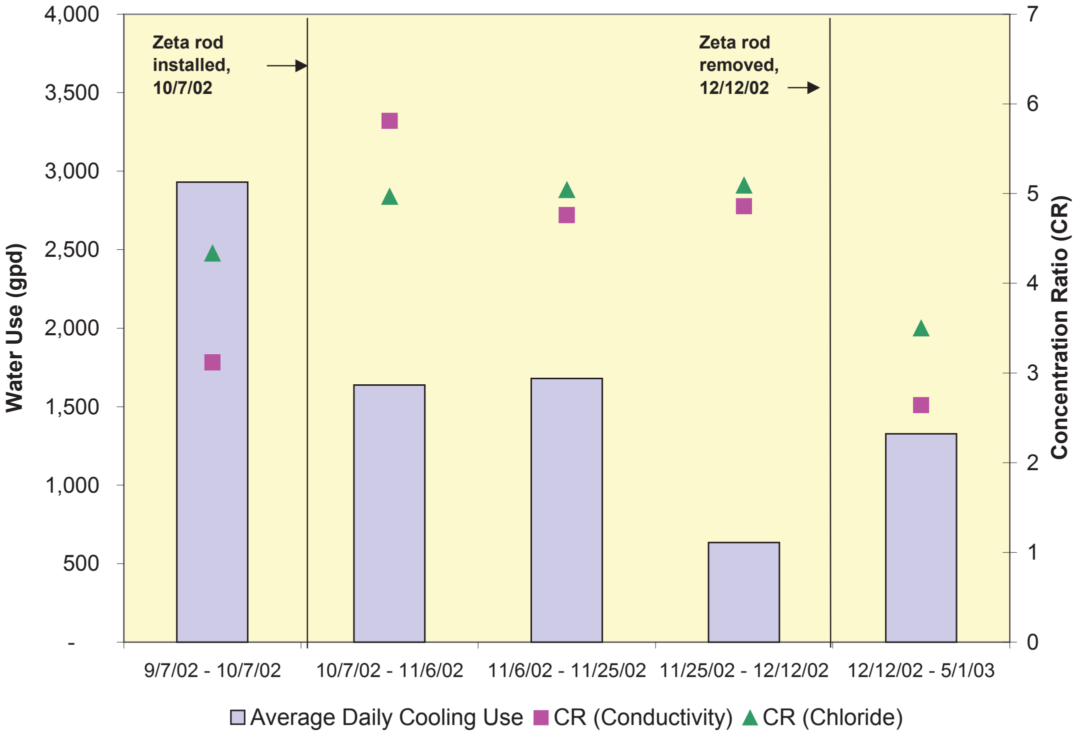


Figure 76: Sun City's average daily cooling use and concentration ratios before, during, and after Zeta Rod treatment.

Water Savings

Figure 77 compares total daily water use and cooling before, during, and after treatment. Both total daily water use and cooling water use decreased during treatment. However, there was not much of a change from the treatment to the post-treatment period. Table 34 shows that cooling savings from the treatment averaged at 1,641 gpd, for 54% savings. The reason that the water use did not rebound after the end of the treatment period was that the owners were planning on replacing the cooler and thus never increased the bleed since any scale build up was not considered a problem.

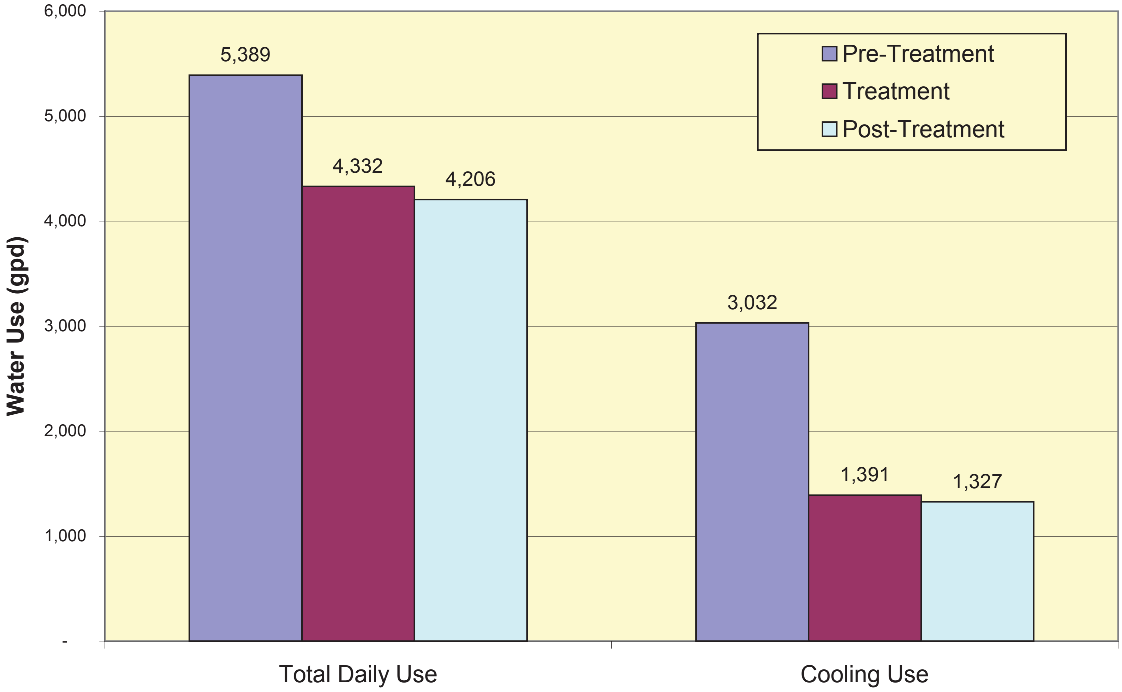


Figure 77: Compares total daily use and cooling use for Sun City from the pre-treatment (4/28/02 - 10/7/02), treatment (10/7/02 – 12/12/02), and the post-treatment (12/12/02 – 12/10/03 for the total daily use and 12/12/02 – 5/1/03 for the cooling use).

Table 34: Sun City's cooling water savings from the pre-treatment to the treatment period.

Pre-treatment (gpd)	Treatment (gpd)	Savings (gpd)	Percent Savings
3,032	1,391	1,641	54%

Performance of Sun City with Respect to Scale and Corrosion

The test of the Zeta Rods was begun on October 7th 2002, and by December 12th 2002 it was clear that the system was not able to prevent new scale from forming. With pH levels of 8.8 to 9.0, calcium levels of 430 ppm and alkalinity of 330 ppm the system became highly unstable. The theory behind the Zeta Rod was that the electro-static charge introduced by the system would create a similar electrical charge on the surface of the micro precipitate particles keeping in them in suspension. Eventually they would drop out of solution onto the bottom of the tank.

In October the system was not in great shape, and there was a thin coating of scale on the pipes, as can be seen in Figure 78. This scale, however, was smooth, and the manufacturer promised that it would be removed by the system. By December, as shown in Figure 79 and Figure 80 there was clearly new scale forming all over the pipes. The manufacturer was not able to suggest a reason why the system did not perform, and it was decided to terminate the test in December 2002. Since that time the entire cooling tower at this store has been replaced as part of routine maintenance and for reasons not related to the outcome of this test.

Table 35: Chemical parameters at Sun City before and after retrofit (mg/L)

Parameter	Ave Feed Water	Tower Water 10/7/02	Tower Water 12/12/02
Calcium	90	430	230
Alkalinity	88	330	270
Conductivity	662	2700	3305
Chlorides	128	650	650
pH	8.2	9.0	8.8
LSI	0.13	2.20	1.70
Ratios:			
Calcium		4.78	2.56
Alkalinity		3.77	3.09
Conductivity		4.08	4.99
Chlorides		5.10	5.10

Figure 78: Sun City at start of test (October, 2002)

Figure 79: Close-up of scale on Sun City tubes in December 2002

Figure 80: Wide shot of scale on Sun City tubes in December 2002

Discussion of Sun City

During the period when the test was being run, from October through December 2002, water use for cooling purposes decreased by approximately 1600 gpd, which represented a 54% reduction in cooling water use. The chemistry of the circulating water in the system showed a strong tenancy for scale formation. At 5.5 cycles of concentration the LSI readings were 2.2 in October and 1.7 in December. Calcium levels dropped significantly during this period while conductivity and chlorides rose or stayed the same. This indicates that calcium was leaving solution during this period. Some of this may have dropped out as the manufacturer planned as a harmless powder on the bottom of the tank, but, unfortunately a significant portion of the calcium was scaling out on the cooling pipes as can be seen in Figure 79 and Figure 80.

USC

The USC store was the second store used to test the Zeta Rod system. The test there was begun October 7th, and on November 25th the manufacturer replaced the first rod with a larger unit in order to try to eliminate the scale formation that was noted in October.

Post-Retrofit Daily Water Use

Figure 81 shows the average daily cooling use and concentration ratios for USC while the zeta rod was in place, as well as just before and after. Once the zeta rod was installed, water use dropped from about 4,400 to about 2,700 gpd. In an attempt to curb scaling, the original zeta rod was replaced with a larger one on 11/25/02. In the interval following that, water use reached its minimum value of 2,100 gpd, and the concentration reached its maximum of 6.8. After the zeta rod was removed, water use ranged from 2,800 to 5,300 and concentration ratios were around 2.5.

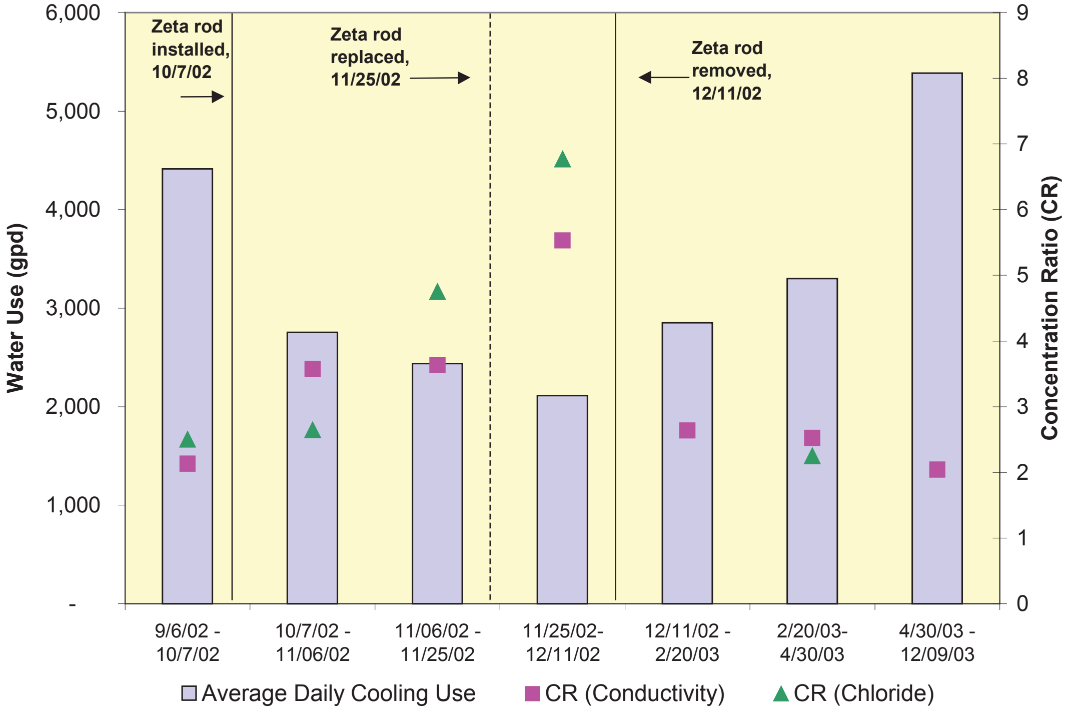


Figure 81: USC's average daily cooling use and concentration ratios before, during, and after zeta rod treatment.

Water Savings

Figure 82 compares total daily water use and cooling use before, during, and after the treatment. Although total daily water use increased slightly, cooling water use decreased. Table 36 shows that cooling savings averaged at 1,844 gpd, for 42% savings. Once the treatment was removed, the total cooling use increased back up to almost 4,500 gpd.

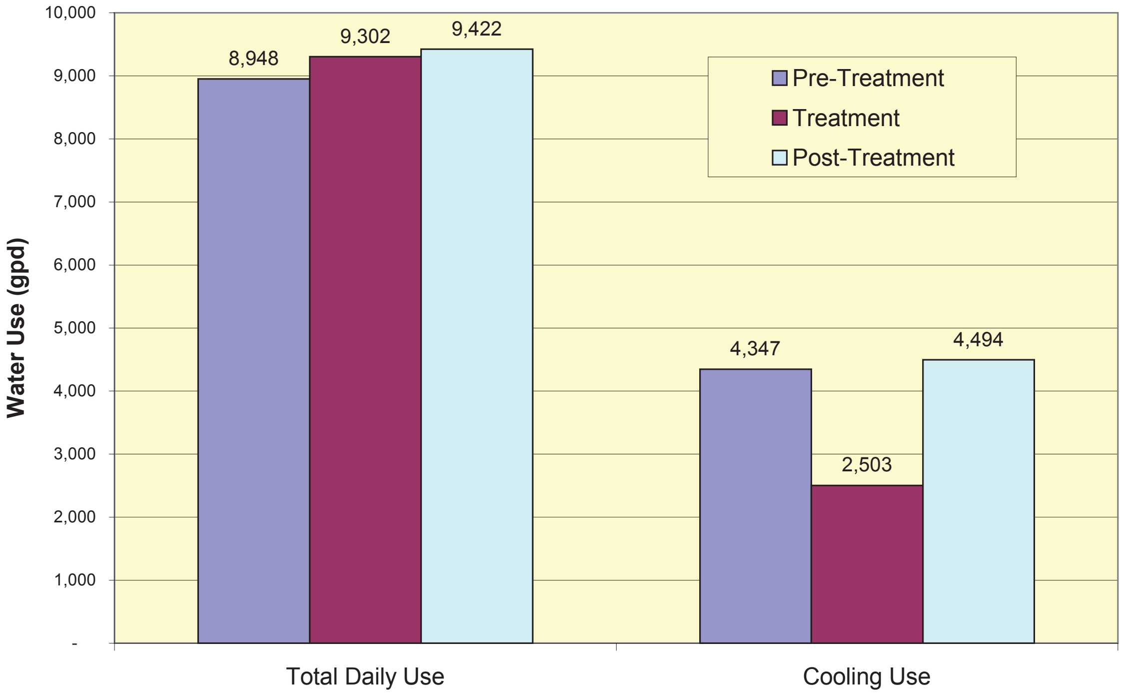


Figure 82: Comparison of total daily use and cooling use for USC from the pre-treatment (4/29/02 - 10/7/02), treatment (10/7/02 – 12/11/02), and post-treatment (12/11/02 – 12/09/03).

Table 36: USC's cooling water savings from the pre-treatment to the treatment period.

Pre-treatment (gpd)	Treatment (gpd)	Savings (gpd)	Percent Savings
4,347	2,503	1,844	42%

Scale and Corrosion Performance at USC

Table 37 shows the chemical parameters in the USC cooling system before and during the test. It is interesting to note that the calcium reading in December 2002, at the end of the test, had dropped in a similar manner as did that in the Sun City Store. As in the case with Sun City, the calcium was leaving solution in this system. The LSI readings in both October and December were over 2 and the pH values were between 8.6 and 8.8, well into the scale forming area. Figure 83 shows the location of the Zeta Rod in the sump of the USC store. The 18” rod was inserted into the sump through a hole drilled in the side of the tank. This was the replacement for the 12” rod used initially.

Figure 84 and Figure 85 show the scale formations that were noted on the tube bundle by December 2002. These deposits were starting at one end of the tank and appeared to be growing towards the other. They were not associated with a local area of poor water spray pattern, as may sometimes happen. It was apparent from the changes in the system between the November and December visits that the situation was progressive, and would continue until the entire tube bundle was covered. Hence the demonstration was terminated and the system was returned to conventional treatment.

Figure 83: Zeta Rod at USC Store

Figure 84: Scale at USC in December

Figure 85: Scale on top of USC tubes in December, 2002

Table 37: Chemical parameters at USC (mg/L)

Parameter	Ave Feed Water	Tower Water 10/7/02	Tower Water 12/11/02
Calcium	143	600	250
Alkalinity	148	540	560
Conductivity	668	1785	3534
Chlorides	68	200	480
pH	7.5	8.6	8.8
LSI	-0.18	2.20	2.10
Ratios:			
Calcium		4.21	1.75
Alkalinity		3.66	3.80
Conductivity		2.67	5.29
Chlorides		2.96	7.11

Discussion of USC

The failure of the Zeta Rod system at Sun City and USC was a major disappointment because if it had performed as promised in the manufacturer's literature it would have represented a breakthrough in water treatment technology. The ability to operate water cooling systems at high cycles of concentration and high pH's without chemicals would greatly simplify the water treatment process and make it far more reliable. The researchers believe it is still worthwhile to test physical systems as they are brought to market, provided their manufacturers are willing to stand behind them and they have a reasonable chance of success.

Dolphin System Operations

The experience with the Scale Viper system was not satisfactory. Both stores in which these systems were uses began to show scale within a month of the installations. The fact that the scale at the Beverly store was relatively light and the way in which the systems were installed (note how the coils were installed in Figure 49) raised the question as to whether it was the technology or the installation that was faulty in these sites. In order to gain more information about a potential useful technology two Raleys supermarkets were visited in the Sacramento area, both of which were using the Dolphin system.

The reason that we believe it is so worth taking a look at every feasible option of this kind is that they do not rely on chemicals so if a successful physical system could be found it would have major environmental benefits.

The two Dolphin systems were located in the Sacramento region of California. One was in Vacaville and the other was in Folsom. The quality of the make-up water at these sites--as measured by total alkalinity, calcium hardness, chlorides and conductivity--was considerably better than that found in southern California as shown in Figure 86. The concentrations of Alkalinty, Calcium, Chlorides and Conductivity in the Sacramento area were all significantly lower than in the Southern California sites. This allows these systems to operate at increase cycles of concentration with less danger of scale formation, which is a major advantage.

The cycles of concentration at these two sites on the day of our observation were between 4 and 5, based on conductivity and chlorides. The circulating water in the systems had conductivity of 1530 and 2763 µmhos (at Vacaville and Folsom respectively). The saturation indices at the two sites were 1.6 and 2.2, so both sites had positive scale formation potential in the circulating water. The Dolphin system was the sole water treatment system being used at these sites for several months prior to our visit and physical inspection showed both to be free from scale build-up.

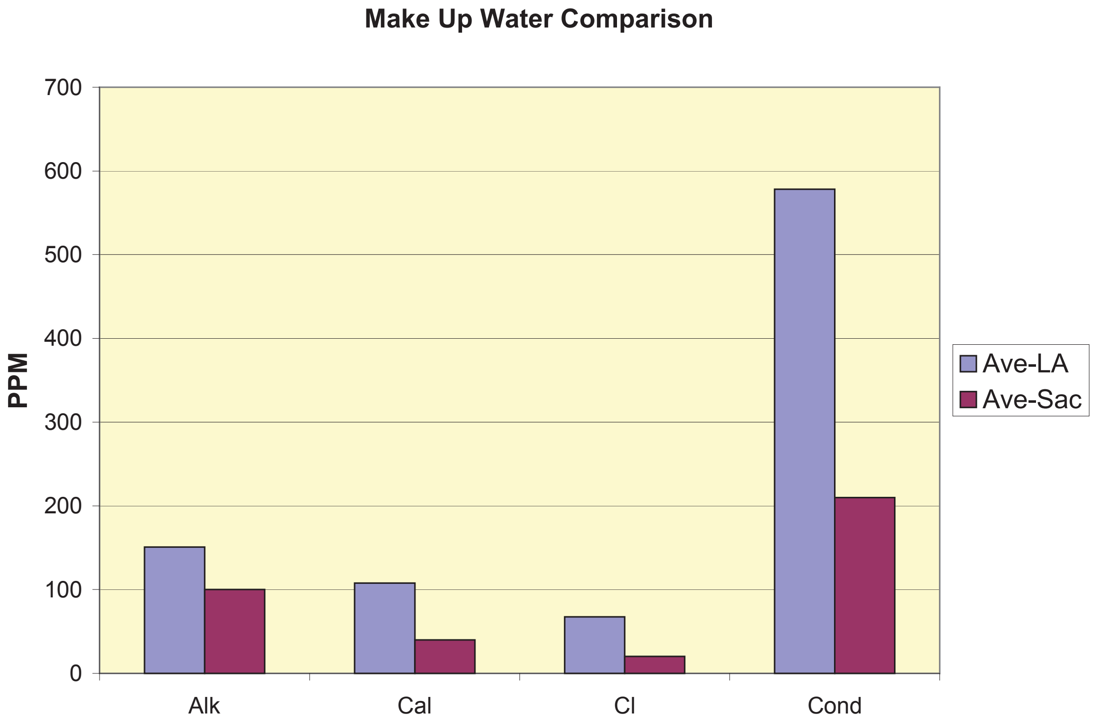


Figure 86: Comparison of water quality at Dolphin test sites to Southern California

Given the positive results that these systems showed, in conjunction with the strong support they received from the maintenance staff at Raley’s, an attempt was made to find one or more supermarket locations in Southern California in which the technology could be tested. Unfortunately, with the strike in place this proved impossible to do. We nonetheless wanted to include this information in this report in hopes of spurring others to pursue this testing. One issue that needs to be addressed is whether the Dolphin systems can operate under scale free condition at the higher levels of conductivity and other scale forming minerals found in the water of southern California. According to the product specifications the system is supposed to tolerate conductivities up to 5000 µmhos so the manufacturer information seems to support the notion that the technology could be used in southern California.

Summary of Water Savings

Since this was a study of water savings the researchers thought it would be helpful to summarize the measured water savings at each of the six stores during the period in which the demonstration study was underway. Even though not all of the technologies were successful, the water savings can all be used for economic analysis since they could just as easily have been achieved using the system that did work, alkalinity control.

Table 38 provides a summary of the water saved at each store during the test period. The average amount of water saved at these stores by increasing the cycles of concentration from the baseline level of 2 to 3 to the test levels of 5-7 was 631 kgal per year (0.63 million gallons or 2.0 acre feet per year). The amount of water saved in the entire Southern California region as stores are converted from conventional to advanced treatment depends on the total number of stores available. The researchers estimate that there are at least 2000 stores of all brands that could be converted, so based on this estimate the total water savings would amount to approximately 3,912 acre feet per year. This represent approximately 0.5% of California’s 800,000 af curtailment from the Colorado River.

Table 38: Water savings summary

Store	Savings (gpd)	Kgal/month	Kgal/year
Arcadia	2135	65	781
Beverly	1021	31	373
Irvine	1047	32	382
Santa Monica	2686	82	980
Sun City	1641	50	601
USC	1844	56	675
Average	1729	53	631

ECONOMICS OF ADVANCED WATER TREATMENT

The economic benefits of use of advanced water treatment are threefold: one, it reduces direct expenses for water and wastewater charges paid by the store; two, it decreases electrical use through keeping scale off of the system pipes; and, three, it increases the life of the cooling system by preventing scale from forming, which in turn reduces the need to acid clean the systems. An economic analysis of each system was conducted to show the relative benefits and costs of advanced water treatment for these typical southern California supermarkets.

Water and Sewer Rates

The water and wastewater rates used for each site are shown in Table 39. All of these values are in dollars per thousand gallons, since gallons were the unit of volume used for this study. They can be converted to $/ccf by multiplying by 0.748. This table shows that the combined water and wastewater rates for this region are not inexpensive, and they average $5.30 per kgal of water. Typical rates for electricity were set at $0.06/kwh.

Most of the water rates are based on some sort of increasing block structure. The exception to this is the Towns of Arcadia, and Sun City which both use flat rates. Wastewater rates are generally uniform with the exception of Irvine, which raises rates for wastewater treatment for use over 7.48 kgal (10 ccf). The Eastern Municipal Water District, which provides service to Sun City is another wastewater exception in that they charge a flat monthly rate for wastewater service that is not tied directly to consumption.

The rates that were used for the economic analysis reflected our analysis of the most likely rate that the stores would be paying for the amount of water they would save by reducing their cooling water use. In the case of Irvine, which uses a water budget approach, it was assumed that the water saved would be in the second tier, or inefficient use, category. Even though the individual store in the study may not be actually this rate now it was assumed that as more information becomes available on what constitutes efficient use, low circulation ratio cooling use will be deemed inefficient.

Table 39: Water and wastewater rates

Store	Water Consumption Rate ($/kgal)	Wastewater Rate ($/kgal)	Total Consumption Rate ($/kgal)	Electricity Rate $/kWh
Arcadia	$2.43	$2.72	$5.15	$0.06
Beverly	$2.90	$2.70	$5.60	$0.06
Irvine	$3.70	$1.11	$4.81	$0.06
Santa Monica	$2.33	$3.34	$5.67	$0.06
Sun City	$2.06	‘na’	$2.06	$0.06
USC	$2.90	$2.70	$5.60	$0.06

Note: these can be converted to $/ccf by multiplying x 0.748

Economic Analysis

First Year Costs

A present worth economic analysis was performed for each store in which the costs for installation and operation of the advanced water treatment system, alkalinity control, were determined and compared to the present worth of the savings associated with the program.

Setting up an alkalinity control program requires certain hardware that would not be needed for conventional treatment. The researchers assume that all of the systems already have a water meter on the inflow line with a pulse output and a solenoid valve on the bleed line to control blowdown. The researchers do not believe that meter on the bleed line is practical since our experience is that these tend to plug with debris and are not reliable. As long as accurate information is available on total inflow and cycles of concentration then the bleed from the system can be calculated with accuracy equal to or greater than measurements from unreliable meters. The additional equipment needed includes:

A programmable controller capable of feeding an acid/inhibitor mixture on the basis of pH, and at least three other chemicals based on flow or time schedule. The controller should log conditions in the system so that the history of the system operations can be documented. A unit similar to the Chemtrol CT-3000[23] is considered optimum.

A modem for remote communications and programming of the controller. This is a very useful item since it allows operators to check the status of the system on a daily basis and dispatch technicians any time problems are noted. This capability proved useful on several occasions during the test when chemical pumps failed or other disturbances occurred. Having remote communication should also allow these systems to be visited less frequently.

Chemical feed pumps. Many conventional systems operate with just a single chemical fed by a drip line. This is not possible with alkalinity control. Typically two chemical feed pumps are needed: one for the acid mixture and one for the corrosion control chemicals. A third pump may be used for biocides.

Installation of a bypass line and flow meter for sensors and coupons. A tap off of the circulation lines needs to be made to install a by-pass line in which the pH and conductivity sensors are housed. Corrosion coupons for steel and copper are an option, but are not considered essential for every installation.

The cost analysis assumes that the costs for a standard flow based controller would be at least $500. This amount is deducted from the costs for the alkalinity control since the study focussed on incremental costs to implement this type of treatment. In addition to the additional capital costs there will be an incremental cost to operate an alkalinity control system of approximately $100 per month, over and above amount normally charged for conventional treatment. This will cover the additional chemicals and operator time for testing and system calibration. Table 40 shows the estimated costs to install an alkalinity control system in the first year of its operation. These include the incremental costs for the control equipment and the additional operation costs. This table shows that a total of $4280 has been allocated for system set up, and $1200 for annual additional operating expenses and first year contingency, bringing the total year one costs of these systems to $5480.

---

[23] Santa Barbara Controls, Inc.

Table 40: Costs for alkalinity control in year 1

Item	Costs
Programmable Controller	-$1,680.00
Modem	-$350.00
Chemical Feeds	-$750.00
Installation and by-pass	-$2,000.00
Sub-total	-$4,780.00
Costs for standard	$500.00
Incremental Cost	-$4,280.00
Incremental Op Costs and contingency	-$1,200.00
Total Included Costs	-$5,480.00

Life Cycle Costs

A 25 year life is assumed for the typical supermarket evaporative condenser. Over this period it is assumed that the annual operating costs for an alkalinity control program will increase by 2% over the general rate of inflation. This takes into account additional costs to replace sensors, faulty pumps and perform periodic tests for corrosion etc. In addition, it is assumed that in year 10 some parts will need to be replaced in the system and have allowed $2000 for this purpose. Likewise in year 20, a larger maintenance event is scheduled with $4000 allowance for new parts and equipment. All of these costs are included in an annual economic model and brought back to a present worth using a discount rate of 5%. Because all of the systems were identical they all had the same set of costs, which amounted to approximately $27,000. This is the present worth of all of the capital and operating costs to conduct an alkalinity control program in a typical urban supermarket evaporative condenser.

Life Cycle Savings

Over the assumed 25 year life cycle of a supermarket evaporative condenser there will be dollar savings attributable to the advanced water treatment in three areas:

reductions in water and wastewater charges, reductions in energy costs due to having cleaner coolers, and reductions in maintenance to the system brought about by not having to acid clean the systems to remove scale.

Savings due to water and wastewater bills are the simplest and least controversial since they can be observed directly from the water use data. Water and wastewater savings were calculated from the observed water use reductions in each store and the current water and wastewater use fees. To be conservative it was assumed that in the first year only 25% of the normal water savings were obtained since the system was probably not in operation for the full year. At the same time the researchers allowed the full $1200 incremental costs in order to allow for an additional contingency at start up.

Savings from reduced energy use are less clear cut. This study was not able to show reductions in energy use since at the start of the study all of the systems were free from scale, hence the energy use response as the systems were de-scaled could not be observed. Savings from reductions in energy use, however, are generally accepted as a by-product of scale free operations, so it is reasonable to assume that a well maintained system, such as was achieved at the Beverly store, would result in a 5% reduction in energy use in the stores. So energy savings equal to 5% of the baseline energy use of each store were allowed with an electric rate of $0.06/kwh. An inflation factor of 3% was assumed for both water and electricity fees.

Better water management can also extend the life of the evaporative condenser. The typical operation of conventional systems relies on acid cleaning as a fairly routine part of the program. These cleaning events are often not recorded, but technicians interviewed during the study freely admitted to adding acid to reduce head pressures on the compressors on an “as needed” basis. One only needs to look at the photos of the coolers above to see the effects of the corrosion. The cooler at Irvine, which was 13 years old was in such an advanced state corrosion that one could push a finger through the end wall of the tank. The copper tubes were heavily eroded and the tube bundles and walls had to be replaced. Based on this experience it is reasonable to assume that a well run water system, that prevents scale from forming on the system can forestall a major overhaul of the system, resulting in savings of $50,000. This is the amount required to replace the tube bundles and rebuild the walls of the evaporative condenser. At the 5% discount rate, this amounts to a present worth of approximately $24,000.

Table 41 shows a summary of the economic analysis for each store. The water savings are based on the observed reductions in water use when the cycles of concentration were increased to the range of 5.5 to 6.0. The combined water and wastewater rates were obtained from the respective utilities. Baseline energy use was obtained from the historical utility bills. Discounted savings are shown for water/wastewater, energy and avoided maintenance. Total savings equal the sum of these three categories. The savings are then compared to the present worth of the costs to install and operate an advanced water treatment program at the stores, and two benefit cost ratios are calculated: one based on the ratio of *total* savings to costs, and one based on the ratio of *just the water and wastewater* savings to costs.

If one is willing to assign even a modest value to energy and avoided maintenance attributable to advanced water treatment then the case for switching over is most compelling. The benefit cost ratios in this case range from 5 to 10. Even if one totally discounts any savings from energy and maintenance, however, the case is still very good. In four out of the six sites the benefit cost ratios are greater than 2, and they range from 2.16 to 3.93. In the two sites that are less than 1.0, one, Sun City, charges for wastewater on a flat rate and the other, Irvine, provides a water budget that is probably too large to capture the inefficiency of the cooling water use. The stores in Arcadia, Santa Monica, and Los Angeles all pay sufficient water and wastewater fees to easily justify the use of advanced water treatment.

Table 41: Summary of Cost and Benefits

Store	**Water Savings**	**Combined Rates**	**Baseline Energy Use**	**Savings Present Worth $**				**Cost PW**	**Ben/Cost Total**	**Ben/Cost Water**
	kgal		**kWh**	Water/WW	Energy	Maint.	Total			
Arcadia	781	$5.14	1,421,174	$69,876	$74,213	$24,051	$168,139	-$26,946	6.24	2.59
Beverly	627	$5.60	2,919,168	$61,118	$152,437	$24,051	$237,606	-$26,946	8.82	2.27
Irvine	496	$2.97	3,295,477	$25,642	$171,819	$24,051	$221,512	-$26,946	8.22	0.95
Santa Monica	1072	$5.67	2,500,000	$105,801	$130,848	$24,051	$260,700	-$26,946	9.67	3.93
Sun City	601	$2.06	1,671,120	$21,550	$88,156	$24,051	$133,758	-$26,946	4.96	0.80
USC	675	$5.60	2,333,280	$65,797	$122,261	$24,051	$212,108	-$26,946	7.87	2.44
Average	709	$4.51	2,356,703	$58,297	$123,289	$24,051	$205,637	-$26,946	7.63	2.16

CONCLUSIONS AND RECOMMENDATIONS

This study has shown that in real world conditions, water savings are achievable from increasing the cycles of concentration of the evaporative condensers in most urban supermarkets. The six stores that participated in this study saved an average of 631 kgal (844 ccf) of water per year by increasing the cycles of concentration from the neighborhood of x3 to x6.

There is also significant water saving potential from in-store uses. These are more difficult to measure, but include: installation of high efficiency sprayers and aerators, flow control devices on water supply lines, retirement of garbage grinders in favor of composting produce waste, use of high pressure sprayers for cleaning the meat and produce departments instead of low pressure garden hoses. Use of ULF toilets and urinals were already a standard practice in the stores in this study. The store management can encourage water conservation by seeking reports of leaks and waste from the employees and rewarding employees who assist with conservation efforts.

Prior to the study intervention, these stores used an average of 3.5 million gallons of water per year (4680 ccf). This was split remarkably evenly between cooling use, at 4,128 gpd, and all other in-store uses, at 4,123 gpd. The cooling use was divided into approximately 2400 gpd for evaporation and 1680 gpf for bleed. Using the relation that concentration ratio equals the ratio of the feed water to the bleed water, this implies an average concentration ratio for the store under conventional treatment of 2.45.

None of these stores were selected based on any criteria other than their willingness to participate, and they are thought to be typical of most full service supermarkets. The researchers do not see any reason that the results in this study would not be applicable to the entire Southern California area.

When the capital costs for control and chemical feed equipment are combined with the incremental operation and maintenance costs for an alkalinity control system and brought back to a present worth, the entire incremental cost to install and operate an alkalinity control system equals approximately $27,000.

The present value of the savings in water and wastewater bills was calculated for each store using the applicable water and wastewater rates. These ranged from a low of

$21,550 for Sun City (which charges a flat rate for wastewater service) to a high of $105,800 in Santa Monica. The average savings from water and wastewater charges equaled $58,297, which equals 2.16 times the cost of the program. The actual benefit cost ratios, based only on water and wastewater savings, ranged from a low of 0.8 to 3.93.

The two sites that had water/wastewater benefit cost ratios less than one were atypical. In the case of Sun City, there were no savings attributable to wastewater flow reductions since that system charges for wastewater based on a flat fee structure. In the case of Irvine, they have a water budget system in place which is too generous in its allocation to supermarkets since it allows enough water in the "conservation" rate to include what is clearly an inefficient cooling system, plus inefficient use of water for washing the meat department.

If one includes even modest savings from reduced energy consumption and avoided maintenance of the cooling system the benefit cost ratios increase drastically. If one allows for a 5% reduction in energy costs due to maintenance of cleaner refrigerant tubes, and avoidance of a major overhaul expense of $50,000 in year 15 of the life of the system, due to less reliance on acid cleaning, then the benefit/cost ratios range from 4.96, at Sun City, to 9.67 at Santa Monica. In this case all of the stores show a dramatic benefit from use of advanced water treatment.

Unfortunately, the researchers were not able to demonstrate that either of the non-chemical treatment systems included in this study (The Zeta Rod ™ and the Scale Viper ™) were effective are prevention of scale when the system were operated at 5.5+ cycles of concentration and pH's approaching 8.9. The two systems that were studied, and which promised to achieve scale free operations by their manufacturers, both showed scale formation within 30-60 days of the start of operation. In one case the manufacturer increased the size of the Zeta Rod from 12" to 18" in an effort to reverse the situation, but this proved unsuccessful.

Even though the physical treatment systems did not prove successful in this test, a review of the literature shows that they are based on real physical processes and may have merit. Examination of other physical systems using similar approaches in Sacramento showed that these systems are able to prevent scale at lower cycles without use of chemicals. The problem appears to come when higher mineral water, such as that found in Southern California, is used as make-up. These systems are still worth investigating since the benefits of development of a non-chemical system would be significant.

Of the three systems studied, only the alkalinity control program proved successful, but even here, it was seen that careful attention needs to be paid to the chemistry of the system. There are several key scale forming minerals, and each of them must be controlled to prevent scale problems.

Calcium carbonate is the main culprit in scale formation since the concentration of calcium is normally greater than any of the other scale forming cations, and when combined with carbonate alkalinity (at $pH > 8.3$) it readily forms calcite scale. Even when the pH of the system is kept below the trigger level for calcium carbonate, however, scale can form due to calcium phosphate, calcium sulfate, or magnesium silicate. Each of these can cause problems equal or greater than those cause by calcium carbonate. Examples of this were observed in this study.

It should be noted that a system treated with alkalinity control is potentially unstable. If the chemical feed that keeps the pH at the target level is interrupted for any reason, the pH will rise and the system will start to scale. This points out the importance of being able to use a modem to remotely monitor the system. Even several days of high pH will not cause significant problems, so having the ability to check the systems on a daily basis during the workweek is more than adequate to catch and correct incidents before they turn into problems. It is also possible to use the remote control software to issue a telephone alarm that will alert the necessary person immediately of an excursion from target conditions. These capabilities reduce the need to perform routine site visits and allows technicians to be sent only to those sites that need attention, which in the long run will save labor for the water treatment contractor. With a modem in place it should not be necessary to visit sites more frequently than once a month.

BIBLIOGRAPHY

Cavano, Robert R., *Phosphonates as Calcium Carbonate Control Agents.* The Analyst Journal, Spring 2002, pg 9

Kemmer, Frank N. (editor), *Nalco Water Treatment Handbook, Second Edition.* McGraw-Hill (1988)

Lide, David R. (editor), *Handbook of Chemistry and Physics, Version 2003.* Chemical Rubber Company Press (2003)

Opheim, Dennis, Ph.d. and John Lane, Clearwater Systems. *Biological Control in Cooling Towers Treated with Pulsed-Power Systems*

Sawyer, Clair N. and Perry L. McCarty. *Chemistry for Sanitary Engineers, Second Edition.* McGraw-Hill (1967)

Tellco Water Technologies, *Scale Viper, Electronic Water Conditioner,* (undated)

Zeta Rod--Installation, Operation and Maintenance Manual, Zeta Corporation, 2045 N. Forbes Blvd., Suite 102, Tucson, AZ 85745

The Zeta Story—State of the Art Fouling and Scale Mitigation, Zeta Corporation, 1997

---

[1] Dziegliewski, et al. “Commercial and Institutional End Uses of Water.” American Water Works Association Research Foundation, Denver (2000)

[2] Kobrick, Douglas J, and Mark D. Wilson, *Uses of Water and Water Conservation Opportunities for Cooling Towers.* Proceeding of Conserve 93, AWWA (1993)

[3] See Evapco Maintenance Bulletin 112