INNOVATIVE
CONSERVATION
PROGRAM
Metropolitan Water District
of Southern California

DISCLAIMER

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APANA
Manage Water Like Inventory™

Data Driven
Cooling Tower Optimization

Made possible by a grant from:

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Contact Author:
Frank Burns, Principal Investigator
APANA Inc.
frank.burns@apana.com

Contributing Investigators:
Thomas Pape, Best Management Partners
Kent Sovocool, Sr. Conservation Research Analyst, Southern NV Water Authority
Bill Hoffman, PE, Hoffman and Associates, LLC.
Thomas W. Remmers, PhD, Vice President of Analytics, APANA Inc.
Kristie Lanum, Director of Operations, APANA, Inc.

Technical Contributors:
Matt Heimsoth, Refrigeration Specialist
Mark Johnson, Water Quality Specialist
Barry Willows, Water Quality Specialist

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First and foremost, we thank the Metropolitan Water District of Southern California for creating the opportunity to collaborate with the broad group of specialists who made this study possible.

Thomas Pape and Kent Sovocool were the ones who proposed the deep analysis of actual operating efficiency compared to the potential operating efficiency from a COC perspective. Their guidance on establishing what efficient means despite a wide range of opinions observed enabled conversation and data collection resulting in a map of numerous root causes underling the efficiency gap and enabled insights to improve standardization of efficiency across units. This work could have far reaching impacts.

This project would not have been possible without the commercial and industrial property owners and the water quality specialists who collaborated on everything from data collection to problem identification and resolution.

Foreword

There have been only a few seminal moments in the field of water efficiency in the last 30 years, where materials or methods are discovered to have a dramatic effect on water savings and water saving strategies. The advent of the ULFT was one of the first followed by improvements in other fixtures and fittings. This study has discovered a method that might also have a big impact in dramatically improving water efficiency of operating evaporative cooling equipment and could change the course of utility water efficiency strategies for the commercial sector.

Past methods to improve water use efficiency for evaporative cooling equipment have included strategies to install dedicated water sub-meters meters and TDS controllers in hopes that the tools would lead to maximum water efficiency, as prescribed the equipment manufacturer's instructions.   In most cases, system operators visit the site only once per month. Failures happen between visits. The systems are operated well below optimal efficiency.

It is often said in many industries "that which is measured improves." This study has discovered that which is measured and immediately reported improves exponentially. Reporting problems that happened last month does not affect change. The corrections happen when the facility managers and operators are alerted that a problem is happening right now. And this discovery is transferable to other areas of water conservation. For example, this same method could be used in the landscape irrigation industry to inform customers that the "smart" controller is not operating the irrigation system in an efficient manner, at the very minute the problem is occurring. This is not just about cooling towers, this is about how the water provider interacts with the end user to achieve water efficiency goals.

Thomas Pape,
Best Management Partners

In this fascinating study, APANA explored the benefits of combining high resolution real-time monitoring of water use with analytics and corrective direction to discover major water efficiency considerations, and opportunities, in evaporative coolers and other types of hybrid and evaporative cooling units. With respect to evaporative coolers especially, this is to my knowledge the only in-depth investigation to date using trace end use data to characterize the major failure modes and waste events of the units along with potential gains from improving cycles of concentration. As such, in addition to being an evaluation of a remarkable technology via MWD's Innovative Conservation Program, this report is a significant contribution to the field of water conservation. There are several surprising findings and valuable insights to be found in the work. While I provided small contributions to discussions of maximum analyte concentrations and cycles optimization and some manuscript review, the findings are APANA's and reflect many hours of meticulous work by the company's analytical experts and management. I think you, the reader, will find it stimulating and that it will advance your understanding of this too often unconsidered major end use of water.

Kent Sovocool,
Southern Nevada Water Authority (SNWA)

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Executive Summary

For cities facing scarcity, growth constraints or seeking to improve resilience, this study shows an effective way to build capacity by controlling water and energy waste beyond the city meter.

“The better you measure, the better you can manage.” This quote from Bill Hoffman, PE sums up the findings of this study and the ten years of work that proceeded it. The knowledge gained, the waste stopped, the collaboration that was enabled, all started with one-minute resolution measurement reported and analyzed in near real time. As a conservation infrastructure, this level of measurement and automation had already been demonstrated in building and landscape irrigation applications. Connecting evaporative cooling systems creates a total property water management infrastructure for commercial, industrial and institutional sector properties (CII). As a CII level infrastructure, this approach shows the potential to transform water conservation activities, so they are not only more effective, but provide deeper value and meaningful engagement with end customers, and the technical service providers who influence outcomes.

Part of the vision of Smart Cities is that data and analytics will drive improvement in resilience and sustainability by identifying resource waste and eliminating it promptly. Water is a relevant part of this discussion because even when water is abundant, it is typically the largest consumer of electricity in most US cities. Electricity is used in withdrawal, treatment, and delivery of water to the consumers. Electricity is then needed for wastewater collection and treatment before water can be reused or released back into the environment. When water shortages occur, there is a cascade of impacts that make water efficiency both vital and urgent. This study shows real-time data analysis and reporting helps commercial and industrial water users identify waste and stop it quickly.

Measurement and Analytics - the DNA of Data Driven Optimization
Water use data was collected from water meters installed on cooling unit make-up water supply lines using a Smart City AMI system designed to read water meters once a minute and transfer the data to the cloud in near real-time. Some locations also had blowdown water meters. The water use data was analyzed in the context of a range of unit specific factors (metadata) by an automated analytics engine designed specifically for CII sector water conservation applications. When water use anomalies were detected in the data, the analytics engine automatically mapped alerts citing the problem, the likely cause and provided non-technical photo-driven instructions to stop the waste quickly. Alerts were sent via email to appropriate site staff. The water conservation infrastructure used in this study is deployed in building, landscape irrigation, and evaporative cooling applications in most major cities in North America. The infrastructure is growing and continues to operate even though this phase of the study is complete.

Magnitude of the Problems Discovered
In areas where cooling towers or evaporative condensers are used, they represent between 30% to 50% of the building’s water use and have significant implications for building energy use. There are hundreds of thousands of evaporative cooling units installed in CII applications. Heavy concentrations are in water scarce areas of the Southwest US, where over 90% of this study population is located.

Four categories of failures were shown to produce events that resulted in millions of gallons of water waste between monthly service visits. During 2017, 87% of evaporative condensers enrolled in this study had multiple days of high flow water waste events, or low flow scale events. In low flow scale events, minerals form scale that insulates heat transfer surfaces. High flow waste events cause significant waste of water, energy and money. Low flow scaling events destroy the unit's efficiency to a fraction of what it was before the event and create continuous ongoing energy and water waste for the remaining life of the asset.

Scaling events are so damaging, they are the reason many units are operated with a "safety margin" well below their maximum efficiency levels. In some locations, these "safety margins" are extremely wasteful. Unfortunately, operating inefficiently does nothing to prohibit the failures this study shows are most likely to cause a severe scale event. The data shows significant scale events are caused by a wide range of distinct failures going unreported, and thus uncorrected between service provider visits. Operators who control the water use close to efficient levels do not suffer severe scale events unless there is one of the distinct failures mapped out in this study. The study was successful in mapping out the many root cause failures involved in severe scale events.

Historically, there has not been a convenient, cost effective way to identify problems and then inform facility managers and service operators what the problem is and the appropriate way to contain the problem quickly. Waste continues unabated when owners and operators are unaware problems exist. The use of a data driven approach based on near real-time measurement enables a "security system" approach that provides 24/7 scanning of water infrastructure to pinpoint waste events and guide rapid resolution. This has now been demonstrated to be effective and the results suggest: if you measure better, you can report better and system failures can be corrected faster. Significant water waste and catastrophic failures can be avoided.

Water Savings From Correcting System Failures (Waste + Scale Events)

An average of 2.6 acre feet (AF) of water waste was avoided for each evaporative condenser unit enrolled in the study in 2017 (865,000 gallons per unit). That is a total of 179 AF of water waste avoided at 67 evaporative condenser units. Individual water waste events that would have exceeded one million gallons were identified and stopped in all five types of units enrolled in this study (evaporative condensers, swamp coolers, water cooled roof top AC units, hybrid air/water refrigeration condensers and HVAC cooling towers).

Efficiency Gain Opportunity Analysis

To compliment measurement driven waste event control, investigators sought to determine if study units were being operated efficiently from an optimal maximum cycles of concentration (Max COC) perspective. 2,477 service visit reports from monthly water chemistry service visits conducted across the evaporative condenser units enrolled in this study were examined. Actual COC were compared to the maximum COC possible for the specific units.

The results show more than 75% of the 67 units enrolled in 2017 were operated in the wasteful to very wasteful range, as determined from manufacturer recommendations, when compared to their unit specific Max COC. Operating these same units at an efficient level would save an additional 65 AF of water per year (21 million gallons).

Projecting these savings on a larger scale, if the observed savings at 67 study units were captured at the 10,000 unit level, 29,716 AF of water waste per year could be avoided. Adding in savings from efficiency gain would boosts savings to 40,546 AF at a 10,000 unit level. The table below summarizes the savings.

Savings From	67 Units 2017		10,000 unit level	
	Gal/year	Acre ft/yr	Gal/year	acre ft/yr
Waste Event Save	22 Million	68	3.6 Billion	11,299
Scale Event Save	36 Million	111	6.0 Billion	18,417
Efficiency Gain (opportunity)	21 Million	65	3.5 Billion	10,831
Total	**79.25 Million**	**243 AF**	**13.2 Billion**	**40,546 AF**

Energy Savings

Water saving at the 10,000-unit level has enough embedded energy savings to supply 5,000 to 10,000 homes a year depending on the region. The energy savings from avoiding scale events is also significant. Considering only the embedded energy impact for Southern Nevada and California, the table below shows the projected savings if the observed savings at 67 study units was captured at a 10,000-unit level.

SUMMARY

10,000 Unit Level Embedded Energy Savings Calculation

	Southern NV	**California**
High Use Waste Events	kWH save/ yr (10,000 unit level)	kWH save/ yr (10,000 unit level)
kWH/K gal	6.82	3.5
Kgals (1,000 gallon units)	3,600,000	3,600,000
kWH avoided (embeded energy)	24,552,000	12,600,000
Households (at 9,000 kWH/yr)	**2,728**	**1,400**
Scale Events		
kWH/K gal	6.82	3.5
Kgals (1,000 gallon units)	6,000,000	6,000,000
kWH avoided (embeded energy)	40,920,000	21,000,000
Households (at 9,000 kWH/yr)	**4,547**	**2,333**
Efficiency Gain Opportunity		
kWH/K gal	6.82	3.5
Kgals (1,000 gallon units)	3,500,000	3,500,000
kWH avoided (embeded energy)	23,870,000	12,250,000
Households (at 9,000 kWH/yr)	**2,652**	**1,361**
Emded Energy Use Avoidable/ yr	kWH save	kWH save
Households (at 9,000 kWH/yr)	**9,927**	**5,094**

Categories of Failures Identified in the Study

Failures that result in high water waste or low flow scale events fall into four categories.

1) Mechanical failure waste events
2) Operational waste events
3) Control failures
4) Failure chains (combination of factors)

A failure, in any of these categories, can lead to millions of gallons of water waste in a year at a single evaporative cooling unit. The million gallons+ per waste event level was measured in all five types of evaporative cooling units enrolled in the study. The largest single high-water use events recorded by enrolled unit type are shown below.

Largest Waste Events by Unit Type

Unit Type	**# of Units Enrolled**	**Largest Single Waste Events Stopped by Unit Type**	**Detail** (see events section)
Evaporative Condenser 100 to 500 tons	100	11.8 million gal/year	Page 53
Roof Top AC Units	2	2.7 million gal/ year	Page 65
HVAC AC Cooling Tower	6	1.8 million gal /year	Page 64
Hybrid Air/Water refrigeration condensers	4	1.5 million gal/ event	Page 67
Swamp Cooler	2	1 million gal/ year	Page 66

The event analysis section shows case examples of what can happen at evaporative cooling units in the built environment. Capturing savings across the built environment means identifying and stopping these types of events quickly. The results of this study come from the level of automated event identification and control demonstrated in the case examples in section 3.

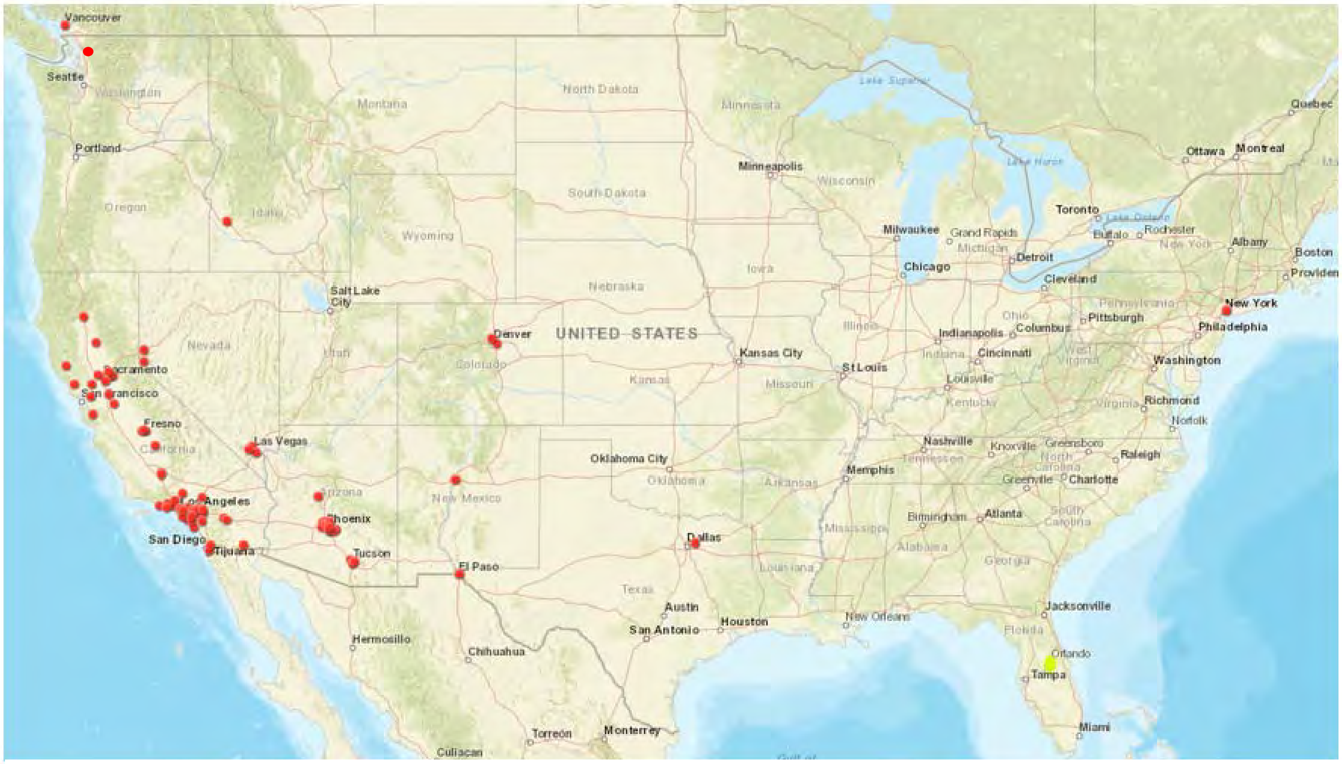
Other Study Accomplishments

A. Mapped root causes for the failures observed across enrolled units.
B. Developed a Key Performance Indicator (KPI) that allows normalization and comparison of efficiency across all units.
C. Developed a web application to collect monthly service visit data, creating a path to operating closer to potential max efficiency targets at all units.

Enrollment Map - Sep 2018

Note: Savings analysis was calculated using only the 67 evaporative condenser units with enough 2017 data to represent a full year savings. Units enrolled late in 2017 and the other evaporative cooling systems enrolled provided powerful case examples.

North America



AZ	CA North	CA South	CO	ID	NM	NV	NY	WA	Texas	Canada	Japan	Total
20	26	40	2	1	1	15	2	1	2	2	2	114

Japan

Enrollment Detail

100 to 500 Ton Evaporative Condenser Units = 100

Multi 1,000 Ton HVAC Units = 6

Other:

Hybrid Condenser Units = 4

Roof top unit AC locations = 2

Swamp cooler location = 2

Water quality service Companies = 22

Water quality service technicians = 105

Average days between service visits = 31.6

1. Study Summary

Hypothesis:
Significant energy and billions of gallons of water per year can be saved by identifying, reporting and quickly solving distinct mechanical and operational water waste events that are found by continuously scanning meta data profiles for cooling towers.

As part of APANA's commercial activities, APANA captures one-minute measurements of water use and analyzes it in near real time. With over 10 years of measurement and analysis, most end uses in certain commercial landscape irrigation and buildings applications have been characterized. Prior to the start of this study (2016), evaporative cooling applications were a relatively minor part of APANA's commercial operations but a surprising source of high-water waste and scale formation events. Separately, the small sample of reports from water quality service visits from the units monitored, showed a possible wide range of operational efficiency. This research sought to expand on existing characterization of specific cooling tower issues and identify the impact that a data driven optimization approach could have on water and energy use in evaporative cooling systems in general but small to medium sized evaporative condensers specifically.

Cooling towers and evaporative condensers have a split problem set. 1) Water waste events and scale events require continuous measurement and automated analytics to provide 24/7 "security system" approach to identify and stop events quickly. 2) Operational efficiency improvement requires on site water test and interaction with expert water quality technicians. This requires data capture and automated expert engagement - not continuous measurement.

Problem Set # 1

The need to pinpoint waste and scale events and fix them quickly.

Problem Set # 2

The need to operate efficiently everywhere

(close to Max COC)

For problem set #1, high water waste and scale events, the technology suite investigators needed was already in use. To address problem set # 2, operational efficiency improvement, a parallel but separate set of activities and tools were needed. Significant work went into developing tools to eventually allow both problem sets to be analyzed and controlled in an automated way.

The following outlines how the research study addressed problem set #1 and #2 and the tools that were developed overcome issues of problem set #2.

1.1 Problem Set #1: Water Waste Events and Scale Events

Data Capture and Processing.

Problem Set # 1

The need to pinpoint waste and scale events and fix them quickly.

Investigators relied on APANA's meter reading infrastructure to read utility grade water meters that are installed on evaporative cooling systems across a variety of commercial and industrial applications. It is helpful to think of the measurement technology used in this study as a Smart City AMI system that reports meter reads every minute. It is not a "normal" AMI system. It is designed specifically for C&I applications where water management requires measurement that is frequent and accurate.

1.1.1 Why One Minute Measurement?

One-minute measurement processed in near real time by automated analytics was used because historic work with 5 minute, 15minute and 60 minute measurements obscured important details. If details are obscured, analytics cannot diagnose anomalies properly. Recommendations based off poorly formed diagnosis create significant problems for engagement with end users.

Prior to conducting this study, investigators had amassed ten years of analysis regarding communication and behavioral interventions that stop water waste in commercial operations. The data suggest people do not like alerts about poorly defined problems. False alarms have been shown to significantly diminish engagement of front-line staff. Through years of practice, the APANA Team has shown that one-minute measurements for most water use applications is sufficient to automate the data processing inside of an analytics suite that is capable of diagnosis and prescriptive guidance.

With accurate, frequent measurements, analyzed in the context of a wide range of site specific factors (metadata), the analytics can pinpoint problems, categorize them and prescribe guidance on what to do to fix the problem quickly. This is shown to improve engagement with end users.

The following provides more detail on the four steps involved in capturing one minute resolution measurement and converting it into information that is actionable across different stakeholder groups.

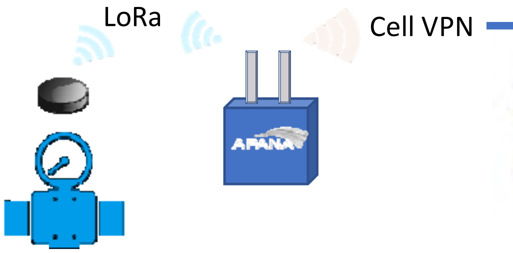
Problem Set # 1

The need to pinpoint waste and scale events and fix them quickly.

Measurement Capture and Processing Steps

The infrastructure used for this study has four steps to capture measurement data and make it useful for stakeholders.

1) MEASURE



MEASURE: A Smart City AMI system that reports every minute from a battery for 10-20 yrs.

APANA's battery powered LoRa endpoints read water meter AMR's once a minute. Data is pushed to the APANA Gateway using LoRa radio technology that enables a 10 to 20 yr battery life. The gateway pushes encrypted data to secure data bases using an AT&T cellular VPN.

2) ANALYZE

ANALYZE: Data is analyzed using analytic engines designed to process large steady data flows in near real time.

Analytics scan the data and pinpoint anomalies. Anomalies are validated and characterized.

3) ALERT & GUIDE

ALERT AND GUIDE: Alerts are mapped with event specific guidance and sent to front line staff for the location.

Alerts use nontechnical language and easy to understand images so they are useful to both line staff and technicians.

4) REPORT

REPORT:
Reports are pushed to specific stakeholders on a schedule.

Dashboards provide immediate access and have diagnostic tools that enable analysis and historical comparisons that make the data useful for research and nonstandard stakeholder needs.

1.1.2 Alerting & Guidance

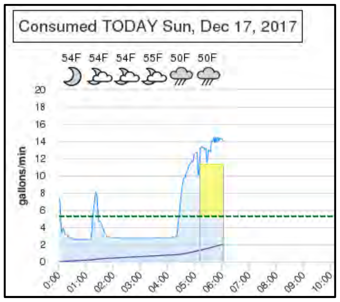
When a failure is identified and categorized by the system, an alert is mapped and sent to the designated staff at the specific location. Instructions for what to do and how quickly to act are mapped into the alert depending on the type and severity of event pinpointed in the data.

Over the course of the study, there were numerous case examples where investigators received feedback citing an event had been found and stopped only to see that the data was still showing an active event.

Below is a visual representation of the three steps.

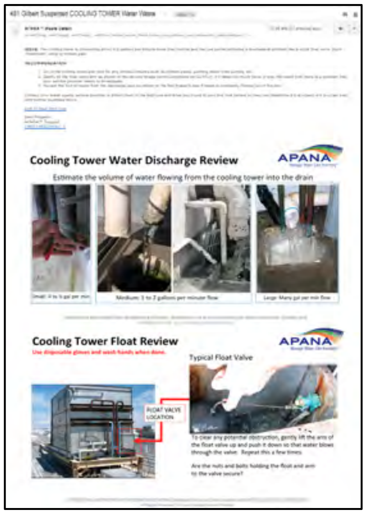
STEP 1:
Failure identified
and categorized.

1) Identified
2) Categorized



STEP 2:
Alert / Guidance
mapped and sent

3) Alert content citing problem and guiding what to do is mapped.
4) Relevant images are mapped into the alert.
5) A Link to real time use inserted.
6) The alert is sent to front line teams responsible for the specific unit.



Cooling Tower Water Discharge Review

Estimate the volume of water flowing from the cooling tower into the drain

Small: [illegible] gal per min

Medium: 1 to 2 gallons per minute flow

Large: Many gal per min flow

Cooling Tower Float Review

Use disposable gloves and wash hands when done.

Typical Float Valve

FLOAT VALVE LOCATION

To clear any potential obstruction, gently lift the arm of the float valve up and push it down so that water blows through the valve. Repeat this a few times.

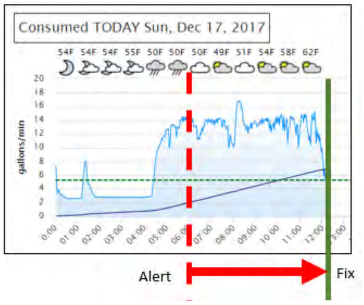
Are the nuts and bolts holding the float and arm to the valve secure?

STEP 3:
Failure fixed.
Fix validated.

7) Front line staff follows simple instructions to find the event.

8) the problem is fixed.

9) the data validates the fix is complete.



Problem Set # 2

The need to operate efficiently everywhere

(close to Max COC)

1.2 Problem Set #2: Efficiency Gain Opportunity

& Tools Designed to Overcome Known Issues.

To identify the possible efficiency gain from maximizing COC and then test the tools conceived to deliver the outcomes, investigators had to:

1. establish what efficient means
2. establish the difference between actual efficiency and the possible Max Efficiency.

The original assumption was that these first two parts would be able to be accomplished quickly. Under this assumption, the study sought to overcome the known issues regarding data capture from water quality specialist visits and a fair way to indicate the actual performance of tens of thousands of units regardless of type, application, geography, operator, or other site specific differences. The tools envisioned and eventually completed as part of the study work were:

- web application to automate the data collection and reporting and,
- establishment of a Key Performance Indicator (KPI) that would provide a fair comparison of actual water efficiency across all units. Working name: “Efficiency Score”.

The following provides details of the different parts of the work involved in addressing problem set # 2.

1.2.1 Establishing Operational Efficiency from a Max COC Perspective

A fair, best management practice driven method for establishing a unit specific optimal efficiency target (Max COC) for evaporative condensers and cooling towers, regardless of their application, location, owner, operator, make-up water quality was a goal of this study but given the complexity of issues and range of stakeholder requirements involved, the path to this goal was not clear until late in the study.

The final criteria established was used to evaluate the actual results recorded in 2,477 monthly service visit records that were analyzed. At each location, the Actual COC was compared to the possible Max COC for the specific unit. The difference between the Actual COC and the Max COC allowed investigators to calculate the volume of water that would be saved for each unit if the gap were eliminated.

Max COC :

Under real-world operating conditions, efficiency has multiple unit specific factors that must be considered. Using a unit specific Max COC approach to determining efficiency normalizes the different factors so a fair comparison can be made regardless of unit type, water chemistry, location, or any of the other factors that make comparisons difficult.

Investigators set out to establish a “reasonable” level to which water quality could be “pushed” so we would have a mechanism of determining what the Max possible COC for a specific unit was and then, evaluate if the specific unit was operating in an acceptable range of efficiency from a water/energy/ risk balance perspective.

Thomas Pape of Best Management Partners and Kent Sovocool of Southern Nevada Water Authority provided guidance on establishing what efficient means from a threshold concentration of limiting variable perspective and how the limiting variable determines a Max COC. Interviews with multiple staff from seven different water quality companies who operate units enrolled in the study provided additional insights to help evaluate the thresholds as well as those published by manufacturers.

After our interviews with different operators, it was apparent there was a range of opinion about the threshold concentrations that could be used under different conditions. Some based on science and current best management practice and some based on practices developed before controls and testing were readily available. The broad range of opinions and unique constraints that impact the universal application of the threshold concentrations for limiting variables took until the end of the study to unravel enough to form a starting point for determining the Max COC for evaporative condenser units. There is a need to emphasize starting point because the limits applied to the data set are slightly low when compared to manufacture recommendations, other published criteria and feedback from Mr. Pape and Mr. Sovocool. The fact two water quality specialists who contributed to this study routinely operate units close to the range specified by Pape and Sovocool provides additional support to the idea the slightly lower study limits should be considered a “starting point.”

Operator insights into the need to avoid scale events and what clients will allow (purchase) were considered as part of the process to create fair efficiency targets. Water quality tests, temperature measurements and operator documentation on unit specific constraints are "standard" components of a water quality service provider visit. This is the information needed to accurately determine the potential Max COC a specific unit can obtain.

A number of operators use water for a set COC regardless of the concentration of the limiting variable or saturation index (LSI typically). The difference between these operators and the operators who consistently approached standards presented by study experts was a significant finding for the study and forced delays and deeper investigation into practical ways to bridge the gap. Toward the end of the study, operators who routinely applied chemical analysis and the best management practice to determine the Max COC for a specific unit, greatly influenced investigators when it came time to set a “starting point” for evaluating operating efficiency of each specific unit.

NOTE: all the units evaluated in the 2017 subset are high quality stainless steel evaporative condenser units in refrigeration applications.

The table below summarizes the range of findings different stakeholders cite as the maximum concentration of the limiting variable typically involved in determining the potential Max COC for the higher quality stainless steel evaporative condenser units common in the study population.

Manufacturer feedback was considered along with significant feedback from operators (Op) across the study population. It is notable that absent any communication between the two groups, the expert opinions provided from investigators who contributed to this study align closely with a couple of the expert operators in this study. The final range of opinion is still broad, but the reasons why are now better understood.

Water Quality "Limiting" Parameter	Units	Manufacturer	Op #1	Op#2	Op#3	Op#4	Op #5	Op#6	Op#6	Op#7	Op #8	Expert Opinion	**Study Limit**
Conductivity (umhos/cm	microohms	3300	2250	2000	3200	6000	3200	cycles only	2000		2800	3,300	3000
Total Dissolved Solids (TDS)	ppm	2050										2050	
Alkalinity - Total (as Calcium Carbonate)	ppm	600			600	500	600	cycles only	550		600	600	600
Ca Hardness (as Calcium Carbonate) CaCO3	ppm	750	500	600	600		600	cycles only	550	600	600	600	600
Chlorides (as Cl) or NaCL	ppm	300	750			750						300	
Sulfates	ppm		500	600						600		250	
Silica	ppm	150		150	150		150			150	150	150	150
LSI (Langelier Saturation Index)	Index	2.8			2.6		2.6		2.1		2.5	2.8	2.6
pH Range Optimization	pH	6.5 to 9.0	8- 9								6.0 to 9.2	7-9.2	

NOTE: Water quality specialists use conductivity to infer total dissolved solid (TDS) concentrations in the water. Conductivity can be monitored and cross checked with hand held testing devices. TDS is an expensive lab test. Accurate conversion of conductivity to TDS may play a role in some of the "range of opinion" that is documented regarding conductivity in this study. To be clear, conductivity is an indicator of mineral content in the water. Minerals cause scale, conductivity helps indicates their likely concentration.

In determining a set of thresholds that could be fairly applied to the information collected from 2,477 water quality service provider visits, investigators considered the unit specific constrains that impact the potential maximum cycles of concentration (Max COC) to which the water can be pushed by comparing actual operating practices at locations where operations conform with established best management practices against threshold values cited by manufacturers, available publications and represented in a proposed addendum to ASHREA Standard 189.1-2017.

For the stainless-steel Evaporative Condensers where the 2,477 service provider visit reports were available, calcium hardness, alkalinity, and conductivity were the common limiting variables documented. Apart from makeup water quality, the applications were either similar enough to allow for a reasonable comparison or have the potential to become similar enough (adding chemical treatment, etc.).

To create uniform standards that enable comparison across all units everywhere, saturation indexes like LSI enable normalization of data and results. LSI is a reliable way to safely determine the Max COC at units that are at risk for calcium deposits. The details required to calculate an LSI are standard parts of an expert water quality service visit.

Where silica or other variables are the limiting factor, the idea of using the threshold of the limiting variable to determine the Max COC the water can be used remains valid.

To extrapolate these findings to other types of units in different applications, a fair score would need to consider unit specific limitations the water quality specialist will be most familiar with. Examples include: metal type, ability to use specific chemical treatment or not, unique local regulations that constrain efficient water use, etc.

Max COC Conclusion:

A Max COC determined by a reaching a threshold concentration of a limiting variable, an LSI limit and/ or a unique unit specific constraint that is documented by an expert operator in a form that can be evaluated considering known best management practices (auditable), allows a fair evaluation of whether a unit is operated efficiently or not.

Efficient is when water is reused to the point the maximum potential number of cycles of concentration for the specific unit is reached but not exceeded.

Having a standardized auditable path to establishing a Max COC for a specific unit creates a path toward a fair, uniform key performance indicator (KPI) that allows for comparison of efficiency across applications, geographies, and equipment types. Current working name for this KPI is "Efficiency Score."

1.2.2 Actual COC Compared to Max COC

To compliment measurement-based water waste and scale event control, investigators sought to determine if units are being operated efficiently from a maximum possible cycles of concentration perspective (Max COC).

2,477 service visit reports from monthly water quality service visits conducted across 67 of the evaporative condenser units enrolled in this study were examined. Actual COC were compared to the maximum COC possible for the specific units.

The results shows more that 75% of the units are operated in the wasteful to very wasteful range when compared to their maximum possible cycles of concentration (Max COC).

Out of 2,477 monthly service visits reports from across CA, AZ, NV between 2015 to Jun 2018, 46% of the reports (1,119) showed COC's 50% below the Max COC possible. 7% (169) of the visit report documented active scaling events. The very real fear of scaling is why units are not operated close to their Max COC. This study and the case examples show that scaling events happen for reasons wasteful to very wasteful operation do not address.

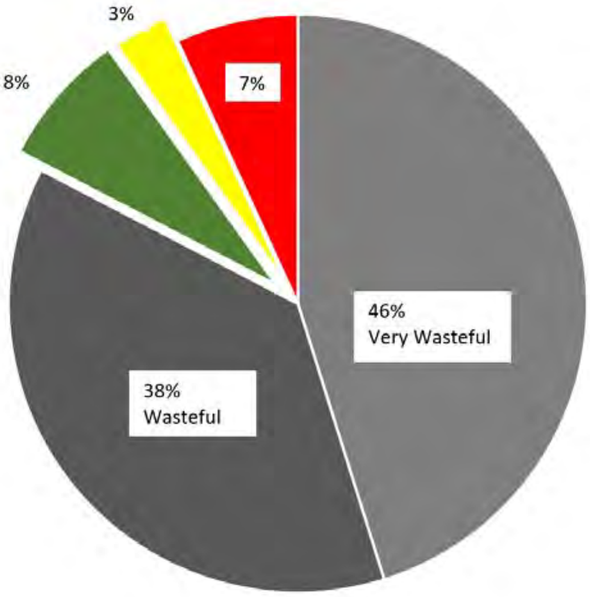
Savings Implications
Migrating units that are operated in a "wasteful" range to a level that is efficient (Max COC range) would save 65 AF of water a year (21 million gallons) over the 67 study units. As a point of reference, if the observed savings at 67 study units was captured at the 10,000 unit level, an additional 10,831 acre ft per year of water use could be avoided.

The risk of scale is the reason cited for operating units at less than the Max COC.

Savings from avoiding scale events would be almost two times savings from efficiency efforts but would also help control the reason cited for inefficient operation. See savings analysis section for details.

2,477 Service Visit Analyzed

EFFICIENT	AT RISK	ACTIVE HARM
85% to 99%	100% to 120%	OVER 120%
186	75	169
8%	3%	7%



VERY WASTEFUL	WASTEFUL
0.0 to 50%	50% to 85%
1119	928
46%	38%

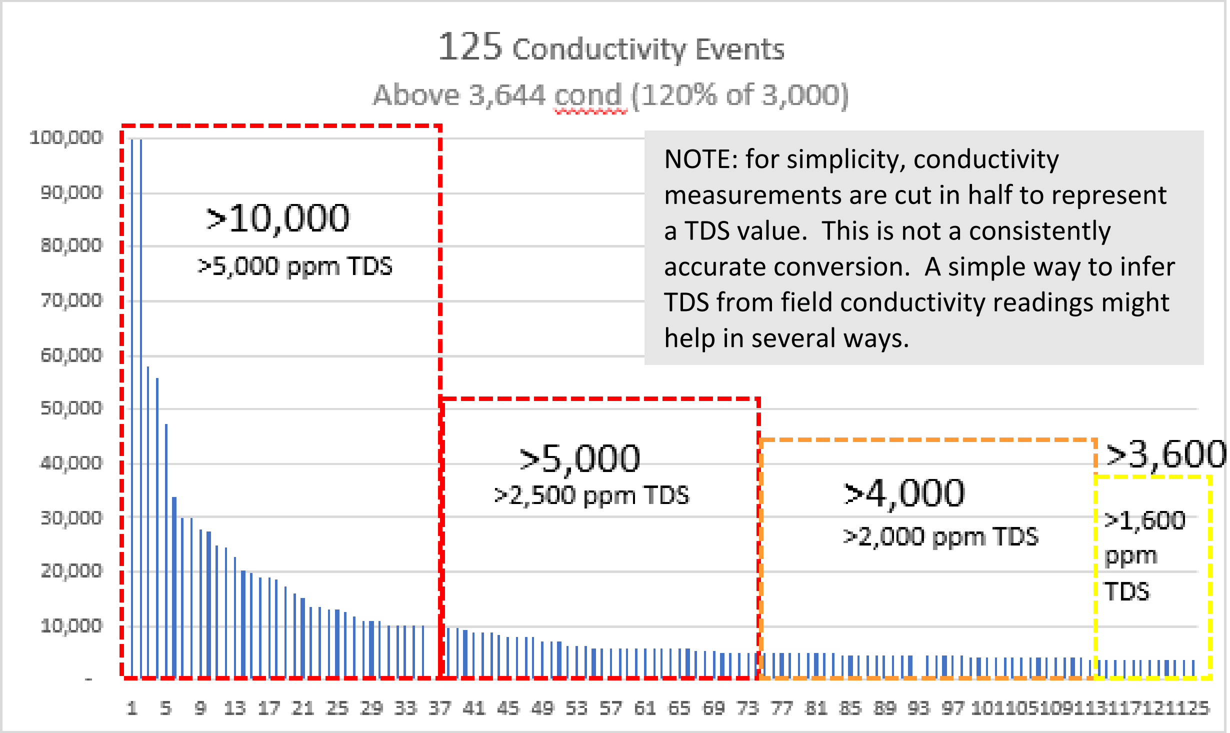
From the 2,477 visit reports, there were 169 possible scale events documented.

Alkalinity in excess of the max threshold was the sole limiting factor in 8 of the 2,477 reports.

Calcium Hardness in excess of the max threshold was the sole limiting factor in 36 of the documented events.

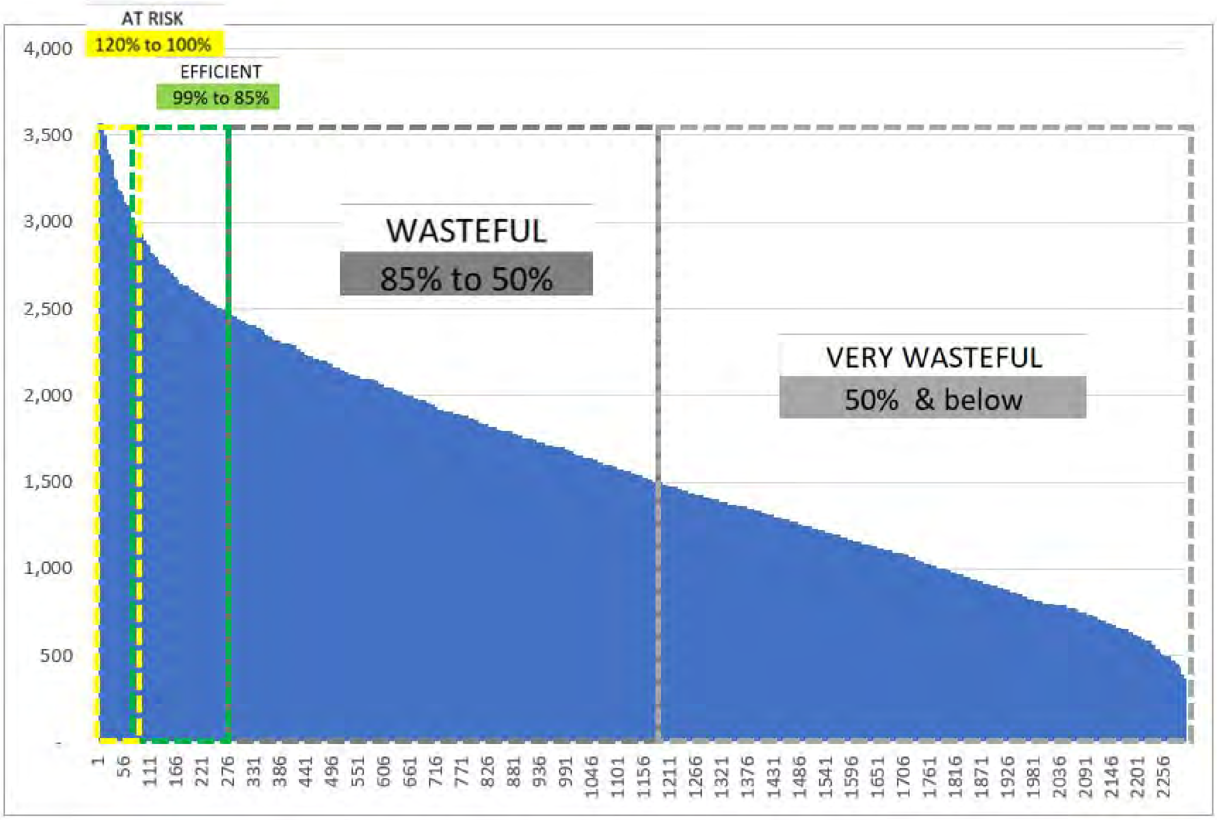
Conductivity was the limiting factor in 125 of the events. 73 of the conductivity events were above 5,000. In evaporative condenser units with higher temperatures for heat transfer surfaces and uncontrolled pH, 5,000 conductivity results in an LSI that suggests a scaling event. To be clear, conductivity infers a total dissolved solids level caused by mineral concentration in the water. Conductivity does not cause scale, it just indicates if the mineral concentration is high enough to mean scaling is likely or not. Conductivity is used in the field because it is a practical alternative to a time consuming and expensive TDS lab test. Many research studies use TDS because it is accurate. The difference deserves further study.

Distribution of scaling events due to high conductivity (TDS)



NOTE: for simplicity, conductivity measurements are cut in half to represent a TDS value. This is not a consistently accurate conversion. A simple way to infer TDS from field conductivity readings might help in several ways.

From the 2,477 monthly visit reports analyzed, most of the evaporative condenser units are operated in the wasteful to very wasteful range when considering their Actual COC compared to what their potential Max COC is.



Details Underlying the Efficiency Analysis

For the stainless steel evaporative condenser units in this study, conductivity, calcium hardness and alkalinity were the limiting variables documented by the water quality specialists who operate the units. Apart from makeup water quality, the applications are similar enough to allow for a reasonable comparison.

Cycling the water use to the point that at least one limit is met, but not exceeded, establishes the Maximum Cycles of Concentration (Max COC) for the specific unit's service visit.

Max COC

The possible Max COC for each specific water quality service visit (2,477), was determined by dividing the "study starting point" threshold concentrations of:

- 3000 for conductivity (1,500 TDS)
- 600 for calcium hardness and
- 600 for alkalinity

by the test results recorded for the make-up water supply.

The variable with the lowest number of possible cycles created the Max COC for the unit for that specific visit.

Actual COC were determined by dividing the values recorded for conductivity, calcium hardness and alkalinity concentrations inside the evaporative cooling unit by the values cited for the make-up water at each individual visit.

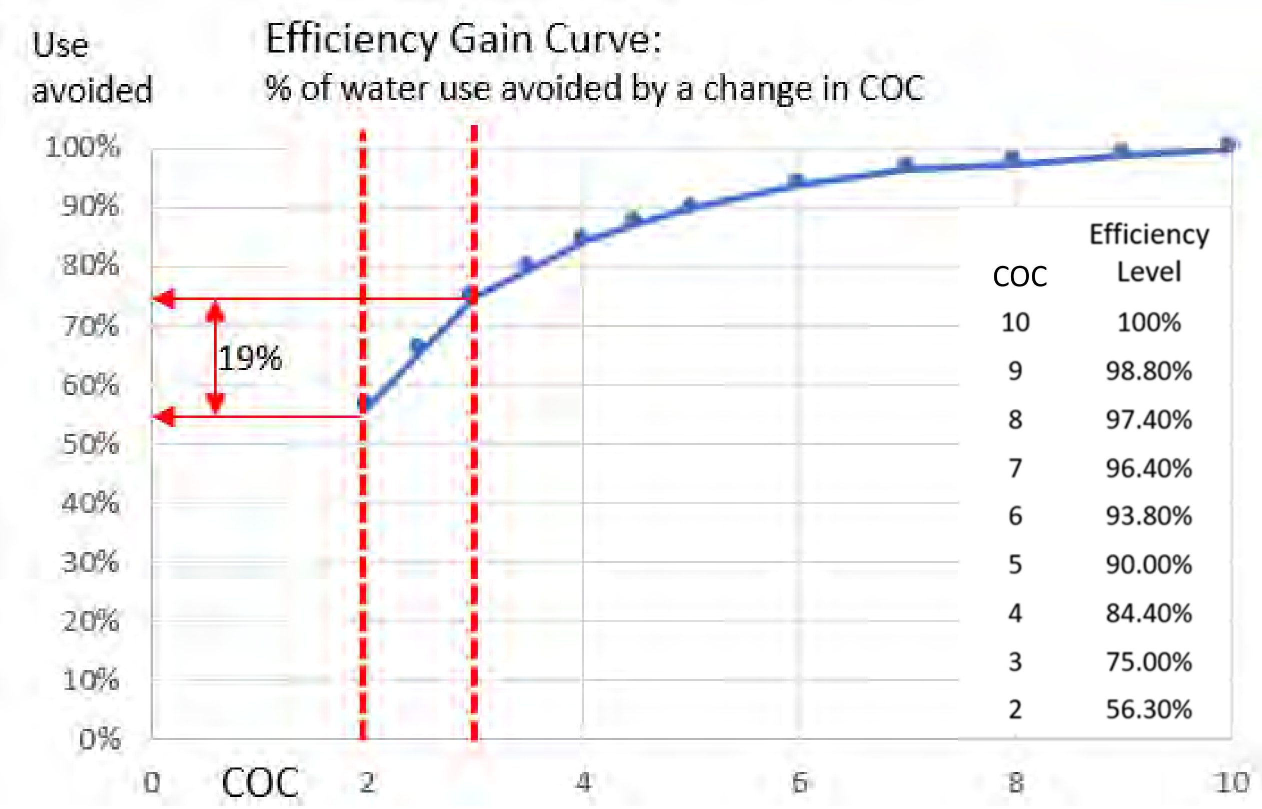
Note: there are unit specific differences, however in the study applications, it is possible to overcome them so uniform efficiency could be obtained. Example: if a unit does not use chemical treatment to control scale buildup, chemical treatment should be installed. This is an example of an operating preference that to date, has been overcome at so many locations it should not be considered a valid site constraint unless there is an agreed upon constraint that is documented.

1.2.3 Efficiency Gain Calculation from Increased Cycles of Concentration (COC)

Increases in cycles of concentration have a diminishing return with respect to the total volume of water saved. To analyze potential savings across the study fleet over time from a COC perspective, investigators compared the average COC, under 12 months of normal operating conditions, to the potential Max COC for the unit. The potential efficiency gain was determined by starting with the Actual COC and adding up the percent gain in water efficiency obtained by moving to the Max COC or 7 cycles, which ever was lower.

The percent efficiency gain by unit for the 12-month period was multiplied by the actual water use over 12 months to determine the volume of water that could be saved if the 67 evaporative condenser study units operate close to their Max COC.

The following table was used to calculate the actual water savings obtainable by increasing Actual COC to Max COC for each of the 67 evaporative condenser study units where enough 2017 data was available.



COC	Efficiency Level
10	100%
9	98.80%
8	97.40%
7	96.40%
6	93.80%
5	90.00%
4	84.40%
3	75.00%
2	56.30%

Investigators are using savings estimates outlined in Harfst (2015) which appear to be representative of findings from a few other sources.

William (Bill) Harfst March 23, 2015

Enhanced Cooling Tower Maintenance Saves Water

March 23, 2015 https://watertechnologyreport.wordpress.com/tag/cycles-of-concentration/

1.2.4 A Web-Based Application to Automate Data Collection and Reporting.

The risk of scale is the most frequent reason individual units are not operated close to their possible Max COC. In rare cases there are other reasons. Regardless of the reason for the variance, accurate measurements and analysis are critical for removing confusion and enabling management across evaporative cooling units everywhere.

The current processes for collecting, evaluating and sharing information are administratively time consuming. This results in disconnects that complicate things to the point stakeholders disengage and the information is not used. In the current processes, reports are generated by an expert operator. They are sent via email to stakeholders. When received they are sometimes put into a folder but infrequently analyzed. Expert data is not trended over time, there is no key performance indicator (KPI) that normalizes the wide range of unit specific factors so relative performance can be assessed. Recommendations for repairs can be missed because they are a line item on a report that is confusing to non-technical administrators.

Interviews and testing with operators and owners showed a functional real world solution should connect the information from a service provider visit to a data base that makes it useful for the operator, owner and other stakeholders in a near real time way.

After a few development cycles, the online web application developed as part of this study, is now capable of capturing information so it can be made useful in ways that help various stakeholders. The current version of the APP is a simple solution that is "fat finger" friendly and aimed at capturing the data and eliminating the operator's administrative hassles.

Additional programming is needed to automatically calculate the Max COC and compare it to the actual COC so an "Efficiency Score" can be issued and guided before the operator finishes their service visit.

The design and development cycle had multiple iterations due to wide ranging feedback from different operators regarding the range of needs for individual units. As investigators gained clarity on how best to reconciled feedback with evolving national standards regarding methods for determining unit specific Max COC, design requirements became clearer.

Basic requirements:

1) Provide an easy quick way to record test results by unit.
2) Capture expert operators' insights that need to be accounted for on a unit specific level.
3) Capture photos directly into the web APP.
4) Automate the legacy processes that consume administrative time and keep data disconnected inside of PDF's and image files that are manually stored in folders and infrequently used.
5) Capture expert recommendations for repairs needed to keep the unit in optimal performance.

Given operator and owner feedback, the APP approach shows promise for connecting the currently disconnected parts that keep actual efficiency much broader than expected given current best management practice standards.

One of the findings from manually entering the 2,477 service provider visit reports into the APANA database was that documentation is currently not standardized. The information cited on the reports is very valuable, but it is displayed in a form that requires significant expertise to understand. There is no context from historic data for the location or comparison to other similar locations.

A significant part of overcoming the issues associated with "problem set #2" involves making it easy for operators to input their test results and measurements. Collecting the measurements in an automated way allows results, as follows, to be generated automatically and delivered in a useful form.

LSI,
Max COC,
Actual COC,
Key Performance Indicator (Efficiency Score)

Once the process is automated, behavioral management techniques involving reporting and recognition can be used to help improve outcomes.

1.2.5 Key Performance Indicator (KPI) for Efficiency

Working name: “Efficiency Score”

This study aimed to create a valid, audit-able performance indicator that is truly comparable across units, geographies, operators, applications, regulatory issues, weather, and any range of unique site conditions.

Establishing a validated, audit-able, KPI opens reporting, recognition and gamification (make efficiency a game) possibilities that do not clearly exist today. This indicator may eventually be a valuable tool for water authorities to help assess rebate program effectiveness, possible regulatory updates and document sustainability impacts of this or any other subsequent innovation applied to cooling towers and evaporative condenser units.

Accuracy of the inputs behind the indicator is fundamental to the function of a KPI. The original study design assumed the basic inputs were known. Again, feedback from operators, owners and real-world complications had to be accounted for to create a KPI that would be fair and useful.

Once the Max COC riddle was solved, a clear path for a KPI that represents if a unit is operated efficiently opened.

The math to calculate the efficiency score is simple but it has multiple steps that, if not automated, almost ensure failure. More work needs to be done to finish the automation, so it is useful across all locations everywhere but, the is path clear.

Step #1: Calculate efficiency gain percentage

Using the efficiency curve, calculate the potential efficiency gain (% of actual water use that can be avoided from moving the Actual COC to the potential Max COC for the specific unit).

Step #2:

Subtract efficiency gain % from 100% to get the “efficiency score.”

Scoring:

1.2.6

Infrastructure Value for Times of Scarcity

When the actual water use is measured and known, the “efficiency score,” can show the actual gallons of water wasted per day, week, month, year by individual evaporative cooling unit.

Knowing the actual water waste by unit could provide authorities with jurisdiction actionable information in times of scarcity or system capacity limitations.

The cost and effort involved in guiding units to operational efficiency or switching them out for units that do not use water would be clear enough to be actionable.

From a management and optimization perspective, investigating why a KPI is out of line would, under ideal conditions, not be necessary because the location operators and owners would have already been informed and should have fixed the problem. Being able to deep dive anomalies though an exception report or dashboard would allow authorities with jurisdiction the ability to evaluate unit specific concerns if they persisted.

2. Savings Analysis and Conservation Potential

The problem set uncovered by data driven interactions with expert operators, manufactures and industry participants revealed complex events and conditions where savings and impact are real but outside of the assumptions the original study design contemplated.

For example, identifying and fixing a low flow events increases water use before the next service visit. However, low flow events create “scale events” that result in continuous ongoing water, energy and chemical waste for the remaining life of the asset. In some cases, descaling processes can reduce some of this impact. There are significant risks and returning the unit to pre-scale event status is typically not possible.

Other complications were unknown failure types that took time and resources to map out. A new category of failure, that we now call “Control Failures,” took investigators until June 2018 to unravel completely. Control failures can have a multi-dimensional failure trains that obscures root causes and results in experts providing explanations that the measurement and metadata analysis do not support (see case study analysis for “Control Failures”).

There are numerous examples where control failures were identified and guided to a quick repair. Examples also exist where failures accumulated significant waste over many months and many units while confusion regarding root cause issues delayed useful intervention. With knowledge gained from study interactions at an AZ unit in June 2018, it became clear that in many past events, waste had been “explained away,” even though the data cited it early and frequently.

Capturing and reporting data to establish Max COC targets by unit and guide operators to run actual COC toward this goal was delayed by the need to overcome the wide-ranging opinions about what “efficient” actually means in the real world. Waste that results from operational preferences or misunderstanding of advancements in best management practices is easy to pin-point when a clear standard for efficiency is established. There were valid technical issues and, in some locations, unit specific regulatory or operating constraints that had to be considered. It took until early July 2018 before the clear path to establishing a fair process to determine the Max COC for specific units over came the differing opinions.

While making it difficult to apply the strict original standards, the real-world experience allowed investigators to expand the knowledge base and provide standards for assessing savings that better reflect the way things are observed to work in real world applications.

2.1 Savings Summary:

Three distinct areas of water waste were characterized and mapped out in this study.

A. Waste Events Measured

Where a failure causes high water use.

84% of the evaporative condenser units had waste and/or scale events observed in 2017.

B. Scale Events Measured

Where a failure causes low water use.
Low water use results in scale deposits on heat transfer surfaces. Efficiencies are cut to a fraction of optimal. Waste is continuous and ongoing for the units remaining life. Risky descaling can return some efficiency but some loss is permanent.

C. Efficiency Gain Opportunity

Where the unit is operated outside of its potential maximum cycles of concentration (Max COC). Fear of adding scale to the heat transfer surfaces is why most units are operated below the possible Max COC. The efficiency gained by moving from the actual COC to the Max COC on the 67 Evap Condensers analyzed in 2017 is the "Efficiency Gain Opportunity."

A yearly water savings estimate for each of these waste areas was calculated by using data from 67 evaporative condenser units with sufficient data and monthly operator visit reports for 2017. Units that were enrolled Q4 of 2017 were excluded from the calculation. HVAC, hybrid and other unit types were also excluded from the savings summary because their enrollment numbers were low compared to the evaporative condensers.

Saving Summary Table

	67 Units 2017		10,000 unit level	
Savings From	Gal/year	Acre ft/yr	Gal/year	acre ft/yr
Waste Event Save	22 Million	68	3.6 Billion	11,299
Scale Event Save	36 Million	111	6.0 Billion	18,417
Efficiency Gain (opportunity)	21 Million	65	3.5 Billion	10,831
Total	**79.25 Million**	**243 AF**	**13.2 Billion**	**40,546 AF**

2.2 High Water Waste Event Savings Calculations

2017 events where detailed data and validation from onsite staff and operators allowed exact calculations of start and stop time compared to the next service visit that would have occurred documented 2,379,969 gallons of waste stopped from the 67 locations with over 9 months of data in 2017. Most of the 1,267 alert events issued received no response from the location staff or the technician. The events stopped but detail was not available to document the cause and validate the exact savings in the same way as the original study design hoped. For these events, the waste recorded by the system (start time to the time the alert was issues) was 1,642,172 gallons in 2017. The system pinpoints waste events in different ways. Certain types of events are pinpointed in a few minutes where events that happen at night and appear to only be wasting water, are submitted early in the morning when facilities staff usually arrives for the day. For these events, the waste is recorded for 240 minutes before issuing the alert. Given the case examples and event history, it is reasonable to assume that these events last all day and would typically run for many days if not months before being identified and fixed. If stopping the event saved 2 days of water waste before a water quality specialist visit would have otherwise found it, the resulting savings is 19,706,065 gallons. The average number of days between service visits is documented to be 31.6. A very conservative 2-day assumption was used to understate the problem while still demonstrating that the problem is significant. It would be reasonable to use 15 days of waste (half of the 31.6 day average between operator site visits).

The volume of water that was documented using full interaction with the location and technical service staff was 2,397,969 gallons in 2017. Adding this amount to the savings estimated for events where local feedback was available is 22,086,034 gallons of water saved from identifying and stopping events at the 67 study locations with more than 9 months of minute resolution water flow data in 2017.

	67 Units 2017		10,000 unit level	
Savings From	Gal/year	Acre ft/yr	Gal/year	acre ft/yr
Waste Event Save	22 Million	68	3.6 Billion	11,299

2.3 Scale Event Impacts

Energy use, equipment damage and operational disruption are cited by refrigeration experts, owners and the water quality experts in this study as the most significant impact of scale events. Once an event happens, options are limited, and the combined costs are high. The increase in the volume of water used is real, but compared to the costs for increased energy, asset destruction and operational disruption, the costs of increasing water use, has historically not been considered a significant part of the total cost of the ongoing expenses associated with a severe scale event.

Water Use Increase Due to Scale

While onboarding locations where severe scale was already present, investigators observed that operators had increased water usage to twice what was observed to be used at similar units that were not severely scaled up.

Cross checking the rationale for higher use with other expert operators from different operating companies and geographies revealed that lowering COC and increasing chemical concentrations appears to be a common response to scale events. By keeping mineral concentrations at a lower level (low COC) and increasing chemical treatments, water quality experts pursue the hope that the built-up scale will slowly be softened and eroded off the copper tube surfaces. The feedback regarding this process is that it takes many months to years to produce results. It commonly requires pressure washing. Given the fact the copper pipes are arranged like a brick of straws, removing scale from the surface of interior tubes has limited effectiveness.

Additionally, both expert operators and available best management practice guides cite that once scale forms on copper pipes, it is easier for minerals to attach and grow thicker scale. Stopping scale growth once it has started is an important intervention.

Refrigeration experts consulted for this study explained that if allowed to continue, scale accumulates on both sides of the copper pipes and fills the ¼ inch gap between pipes. This restricts the space for air and water to flow. In locations where multiple severe scale events occur, mineral deposits bridge the gap and airflow is completely obstructed. In these cases, heat transfer is a small fraction of the original design.

In addition to the water chemistry rationale increases in water use after a scale event, water use increases in units with scale in the following ways:

1) Racks and refrigerant run at higher pressures when heat removal is not efficient. This causes the evaporative condenser fan to operate at higher speeds for longer periods of time. Higher continuous air flow increases evaporation and blow through of the water.
2) When outside temperatures increase, the sump water temps increase and additional city water flow through is used to wash heat out of the sump.

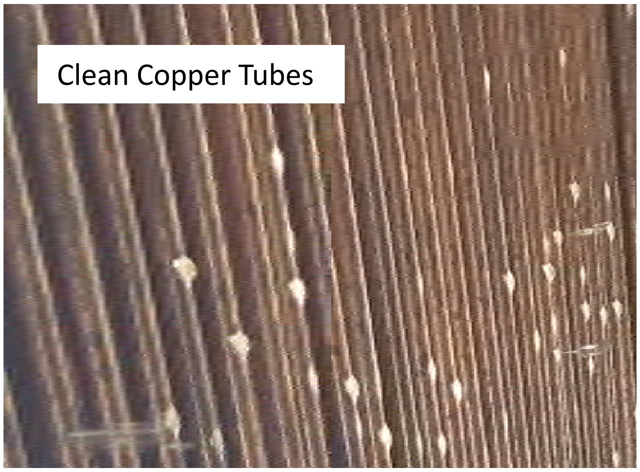
The net result of interventions after a scale event is that more water and energy are used. For experts who oversee a refrigeration system that supports $2 million in perishable inventory, the cost of water in this scenario is not a practical consideration given the other costs involved.

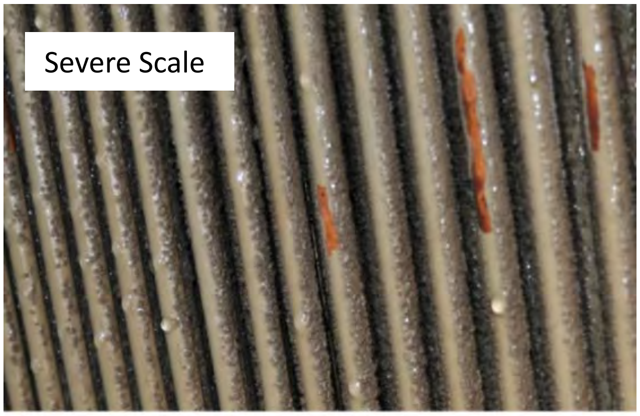
When refrigerant heats up, it changes chemically which can shorten its useable life. Compressors wear faster at higher pressures and temperatures. In one notable situation, a $10,000 compressor overheated and was destroyed after a plumber installed a water softener that diverted water from the evaporative condenser during the softener's nightly regeneration cycle. If the cascade of issues reaches the point that the location's operations are impacted, the cost of disruption become the focus, while increased energy and water use become the tools to get past the emergent issues.

2.3.2 Time to Severe Scale Damage

Multiple water quality service providers report that scale can coat a copper pipe in less than a week if the unit, for whatever reason, does not blowdown. Severe scale happens in a couple of weeks or less. When a scale event starts shortly after a service provider visit, the next visit is an average of 31.6 days away.

More calculation and data analysis can be done however, given operator feedback and references available, it is reasonable to assume that water use increases by 50% after a severe scale event and stays high for the life of the unit or until the unit is descaled chemically (a process that has significant risks and impacts). Although energy use appears to increase significantly, reliable conversion to actual kWHs has not been completed yet. Estimates appear to fall into the 25% to 50% range.



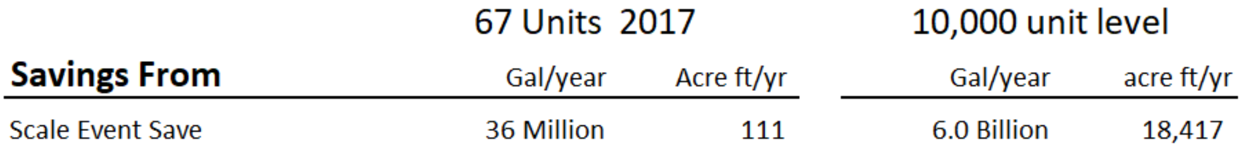


2.3.3 Scale Event Water Savings Calculations

The average daily water use for a typical unit in this study is 5,700 gal/day (slightly more than 2 million gallons of water in a year or 6.38 AF). In 2017, at the 67 evaporative condenser units with water flow and operator service visit data, there were 644 days with low water flow events observed (scale events). Many units had multiple day events or multiple events at the same unit. 37 events had sufficient interaction with site staff and operators to develop case examples.

As previously indicated, severe scale events increase water use by 50%. Under this assumption, the savings range = 37*(2,000,000 gallons x 50%) = 36,000,000 gallons of water a year (110.5 AF).

The savings estimates were also run with the water savings assumptions including a different percent water savings across the 37 units as well as minor percent savings for events where less robust feedback was available. Irrespective of the methodology utilized, scale events cause significant on-going continuous water waste. The total impact on energy and asset health is greater than the impact on water use.



	67 Units 2017		10,000 unit level	
Savings From	Gal/year	Acre ft/yr	Gal/year	acre ft/yr
Scale Event Save	36 Million	111	6.0 Billion	18,417

At a 10,000 unit level, the estimates suggest 18,417 acre ft (6 billion gallons) of water a year is wasted as a result of scale events.

Energy efficiencies are cut to a fraction of optimal. Continuous ongoing water and energy waste continues for the life of the unit or until a risky descale process in implemented.

2.3.4 Energy Use Impact of Scale

During the current phase of this study, investigators are not monitoring electrical consumption at any of the units involved in this study. The energy impact of severe scale events in evaporative condensers has been studied by others. Using estimates from a manufacture's best management practice guide as well as information from Keister*, it becomes clear that severe scale events can increase the energy consumption of a severely scaled unit by 20% to 50%. A more detailed analysis of the actual yearly increase in kWH's of energy consumed needs to be applied to the study findings so the impact can be understood in the context of normalized units (total kWH/yr and or annual households worth of energy, etc.).

To provide a frame of reference for the impact of scale on energy use, Keister* suggests a 1.5 mil coat of calcium scale reduces thermal efficiency by 12.5%. One "mil" = 1/1000 of an inch or 0.025 millimeters. This is less than the diameter of a hair. Severe scale events can deposit over a millimeter of scale in a few weeks at evaporative condenser units where heat exchange surfaces are copper and hold 140 degree refrigerant. This is 40 times the 1.5 mil coat that is suggested to decrease thermal efficiency by 12.5 %. Under the scale conditions observed in this study, unit efficiency would drop to below 50%.

A separate point of reference comes from information published by a manufacturer of evaporative condenser units**. They estimate that a 1/32" deposit of scale (close to a millimeter) increases energy use about 20%. They cite the cost for the additional energy being high enough to cover the expense of a new evaporative condenser once every four years. A low cost for an evaporative condenser in this study is $100,000.

Based on these calculations, severe scale events reduce unit efficiency to a fraction of design standards. Cost for the owner increase but the expense is hidden deep inside of the utility expenses for the location. Unfortunately, utility expenses are usually put into the category of "uncontrollable expenses." Absent monitoring, it is difficult to separate the extra cost. Extremely capable people absorb the expense as a cost of doing business because there currently is no easy way for them to manage it otherwise.

Reference:

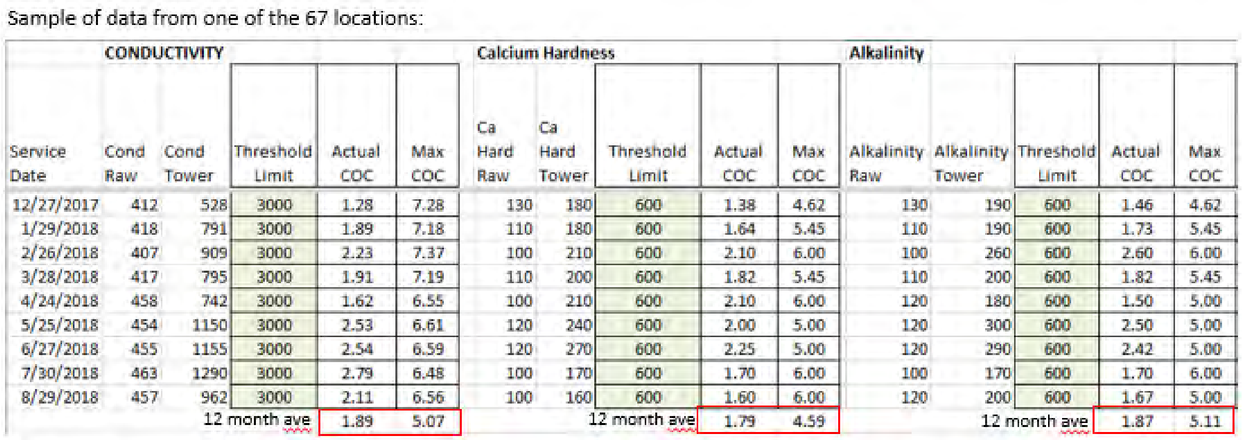
*Cooling Tower Management, Basic Principals and Technology. Timothy Keister, CWT 03/2008

**http://www.baltimoreaircoil.com/english/resource-library/file/639

2.4 Efficiency Gain Opportunity

To create a fair analysis that could be cited in terms of water use avoided per year by efficiency gain, investigators focused on the 67 evaporative condenser units with water use measurements and water quality service visit reports.

For each location, data was analyzed to calculate the actual COC and the possible Max COC for raw water (make-up) and tower water. The results for each variable were averaged over 12 months to get the yearly average COC for each parameter (Conductivity, CaHard, Alkalinity).



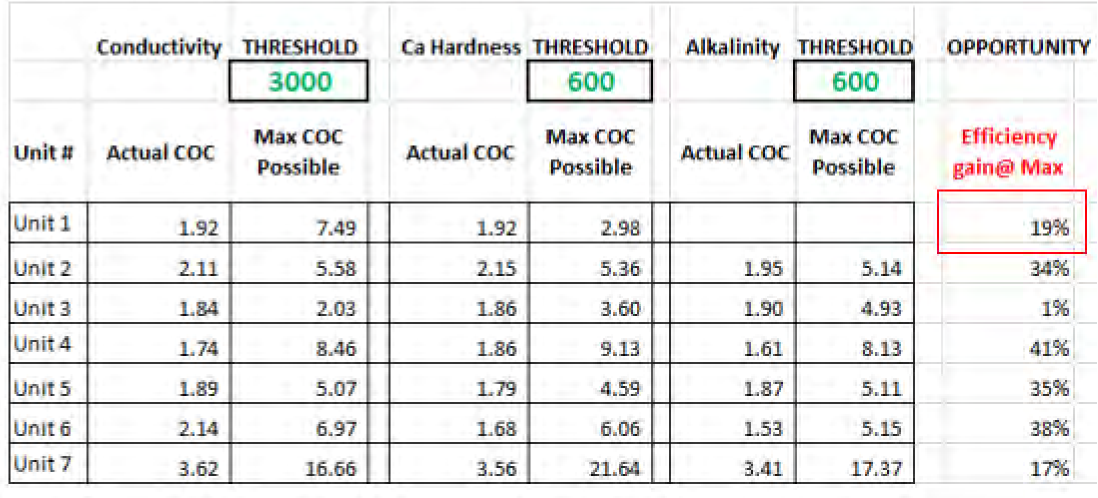
Sample of data from one of the 67 locations:

	CONDUCTIVITY					Calcium Hardness					Alkalinity				
Service Date	Cond Raw	Cond Tower	Threshold Limit	Actual COC	Max COC	Ca Hard Raw	Ca Hard Tower	Threshold Limit	Actual COC	Max COC	Alkalinity Raw	Alkalinity Tower	Threshold Limit	Actual COC	Max COC
12/27/2017	412	528	3000	1.28	7.28	130	180	600	1.38	4.62	130	190	600	1.46	4.62
1/29/2018	418	791	3000	1.89	7.18	110	180	600	1.64	5.45	110	190	600	1.73	5.45
2/26/2018	407	909	3000	2.23	7.37	100	210	600	2.10	6.00	100	260	600	2.60	6.00
3/28/2018	417	795	3000	1.91	7.19	110	200	600	1.82	5.45	110	200	600	1.82	5.45
4/24/2018	458	742	3000	1.62	6.55	100	210	600	2.10	6.00	120	180	600	1.50	5.00
5/25/2018	454	1150	3000	2.53	6.61	120	240	600	2.00	5.00	120	300	600	2.50	5.00
6/27/2018	455	1155	3000	2.54	6.59	120	270	600	2.25	5.00	120	290	600	2.42	5.00
7/30/2018	463	1290	3000	2.79	6.48	100	170	600	1.70	6.00	100	170	600	1.70	6.00
8/29/2018	457	962	3000	2.11	6.56	100	160	600	1.60	6.00	120	200	600	1.67	5.00
			12 month ave	1.89	5.07			12 month ave	1.79	4.59			12 month ave	1.87	5.11

The 12 month average Actual COC and possible Max COC for each variable was used to calculate the possible efficiency gain that would result from operating each unit at the Max COC verses the Actual COC.

The variable with the smallest difference between Actual COC and Max COC, became the unit specific limiting variable.

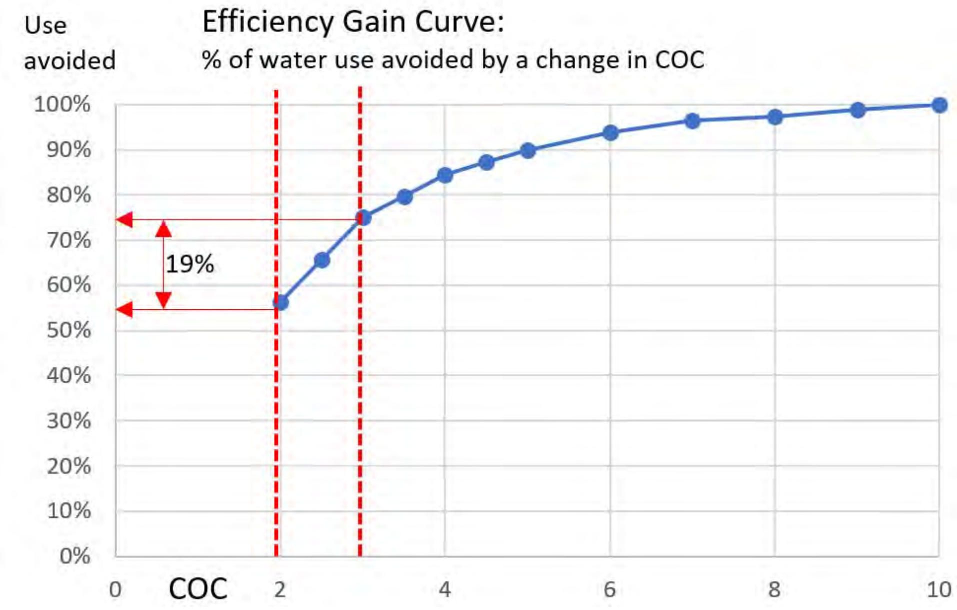
For example, unit #1 in the table below shows an actual average COC for Ca Hardness as 1.92 and the possible Max COC as 2.98. In this case, in theory, the water could have been used for one more cycle.



	Conductivity	THRESHOLD 3000	Ca Hardness	THRESHOLD 600	Alkalinity	THRESHOLD 600	OPPORTUNITY
Unit #	Actual COC	Max COC Possible	Actual COC	Max COC Possible	Actual COC	Max COC Possible	Efficiency gain@ Max
Unit 1	1.92	7.49	1.92	2.98			19%
Unit 2	2.11	5.58	2.15	5.36	1.95	5.14	34%
Unit 3	1.84	2.03	1.86	3.60	1.90	4.93	1%
Unit 4	1.74	8.46	1.86	9.13	1.61	8.13	41%
Unit 5	1.89	5.07	1.79	4.59	1.87	5.11	35%
Unit 6	2.14	6.97	1.68	6.06	1.53	5.15	38%
Unit 7	3.62	16.66	3.56	21.64	3.41	17.37	17%

Investigators used the efficiency gain curve that plots the diminishing returns from increased COC to determine the amount of water that would be avoided given unit specific potential gains in COC.

For the example unit #1, the 19% potential decrease in water use was determined by moving from 1.92 COC to 2.98 COC on the efficiency gain curve.



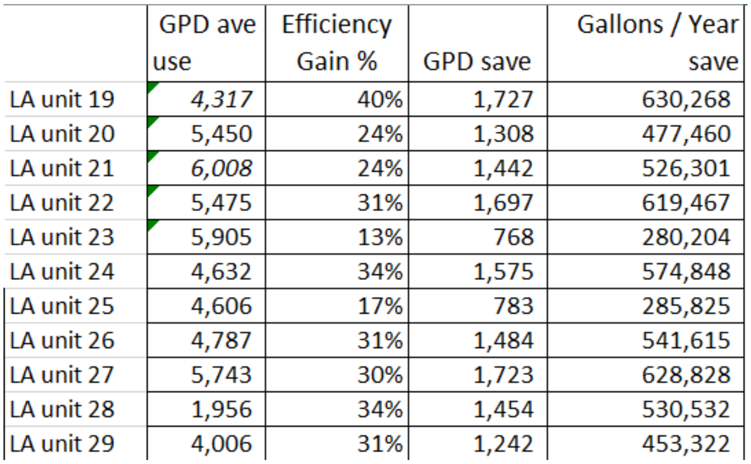
For this one example unit, the 19% is the potential decrease in water use available from moving to a Max COC from the Actual COC. This is called the Efficiency Gain for the unit. The yearly water use at this specific location is measured at 1.86 million gallons. The potential volume of water use that could be avoided by operating at Max COC levels is 354,000 at this one unit.

The evaluation criteria described in the example unit with a 19% water efficiency gain was applied to each of the units in the study.

Below is a screen shot of sample data from the LA region showing how the % Efficiency Gain by unit was converted into actual gallons saved per year.

Sample of unit specific Efficiency gain calculations.

The table to the right shows a sample of how the unit specific water use multiplied by the unit specific potential Efficiency Gain provided a gallons per year of water that could be avoided in each unit were operated at its specific Max COC



	GPD ave use	Efficiency Gain %	GPD save	Gallons / Year save
LA unit 19	*4,317*	40%	1,727	630,268
LA unit 20	5,450	24%	1,308	477,460
LA unit 21	*6,008*	24%	1,442	526,301
LA unit 22	5,475	31%	1,697	619,467
LA unit 23	5,905	13%	768	280,204
LA unit 24	4,632	34%	1,575	574,848
LA unit 25	4,606	17%	783	285,825
LA unit 26	4,787	31%	1,484	541,615
LA unit 27	5,743	30%	1,723	628,828
LA unit 28	1,956	34%	1,454	530,532
LA unit 29	4,006	31%	1,242	453,322

The potential savings opportunity if all 67 evaporative condenser units with full data in 2017 were operated at Max COC instead of the Actual COC is 21,170,549 gallons of water or 64.97 AF.

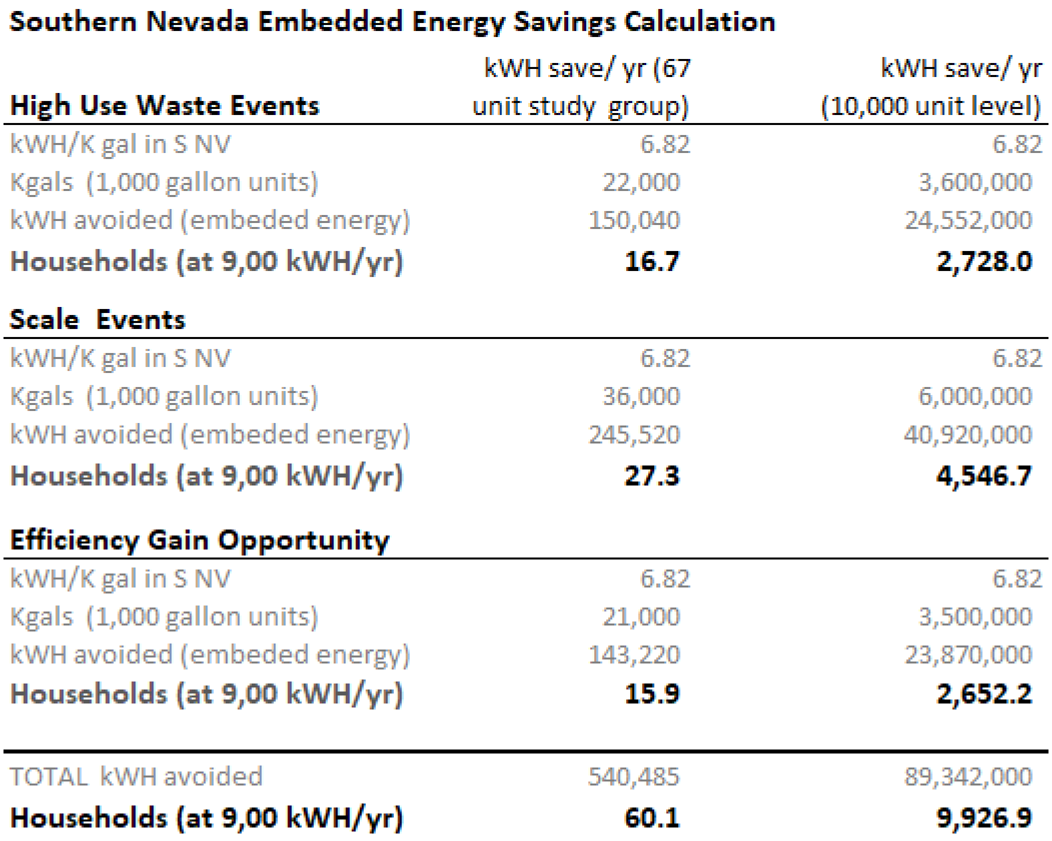
	67 Units 2017		10,000 unit level	
Savings From	Gal/year	Acre ft/yr	Gal/year	acre ft/yr
Efficiency Gain (opportunity)	21 Million	65	3.5 Billion	10,831

2.5 Energy Use Avoided due to Embedded Energy of Water

Electricity is used in withdrawal, treatment and deliver of water to the consumers. Then electricity is needed for wastewater collection and treatment before water can be reused or released back into the environment.

This energy use is called embedded energy. In Southern Nevada, it is estimated to take 6.82 kw hours of electricity per 1,000 gallons of water to complete the cycle. A Stanford study cites a range for central to norther California that translates to 2-5 kWH/ Kgal for embedded energy depending on several factors. The actual energy required to complete the cycle will be different for each region involved. To create a range of reasonableness for the amount of energy that would be saved in a year by eliminating the unnecessary water use that is documented in each of the three water savings categories, investigators ran calculations with a 6.82 Southern Nevada and 3.5 kWH/KGAL factor for California.

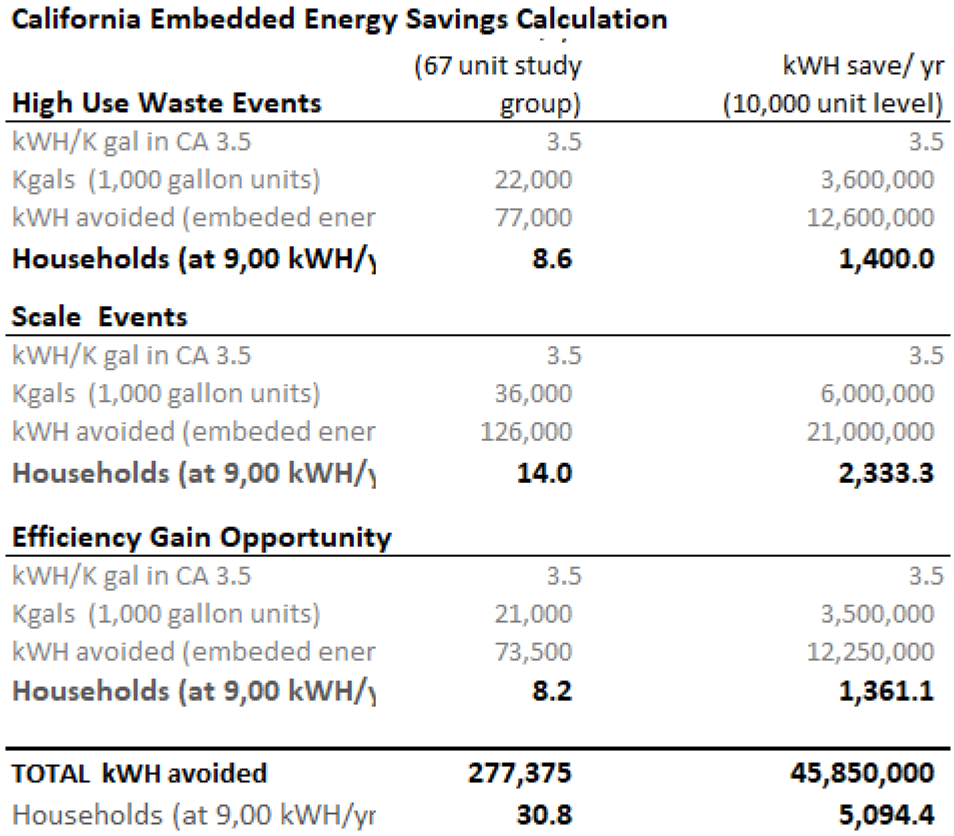
Below is the table for Southern Nevada using 6.82 kWH/KGAL calculation at the 67-unit (2017) level and the projection result at a 10,000 unit level.



Southern Nevada Embedded Energy Savings Calculation

High Use Waste Events	kWH save/ yr (67 unit study group)	kWH save/ yr (10,000 unit level)
kWH/K gal in S NV	6.82	6.82
Kgals (1,000 gallon units)	22,000	3,600,000
kWH avoided (embeded energy)	150,040	24,552,000
Households (at 9,00 kWH/yr)	**16.7**	**2,728.0**
Scale Events		
kWH/K gal in S NV	6.82	6.82
Kgals (1,000 gallon units)	36,000	6,000,000
kWH avoided (embeded energy)	245,520	40,920,000
Households (at 9,00 kWH/yr)	**27.3**	**4,546.7**
Efficiency Gain Opportunity		
kWH/K gal in S NV	6.82	6.82
Kgals (1,000 gallon units)	21,000	3,500,000
kWH avoided (embeded energy)	143,220	23,870,000
Households (at 9,00 kWH/yr)	**15.9**	**2,652.2**
TOTAL kWH avoided	540,485	89,342,000
Households (at 9,00 kWH/yr)	**60.1**	**9,926.9**

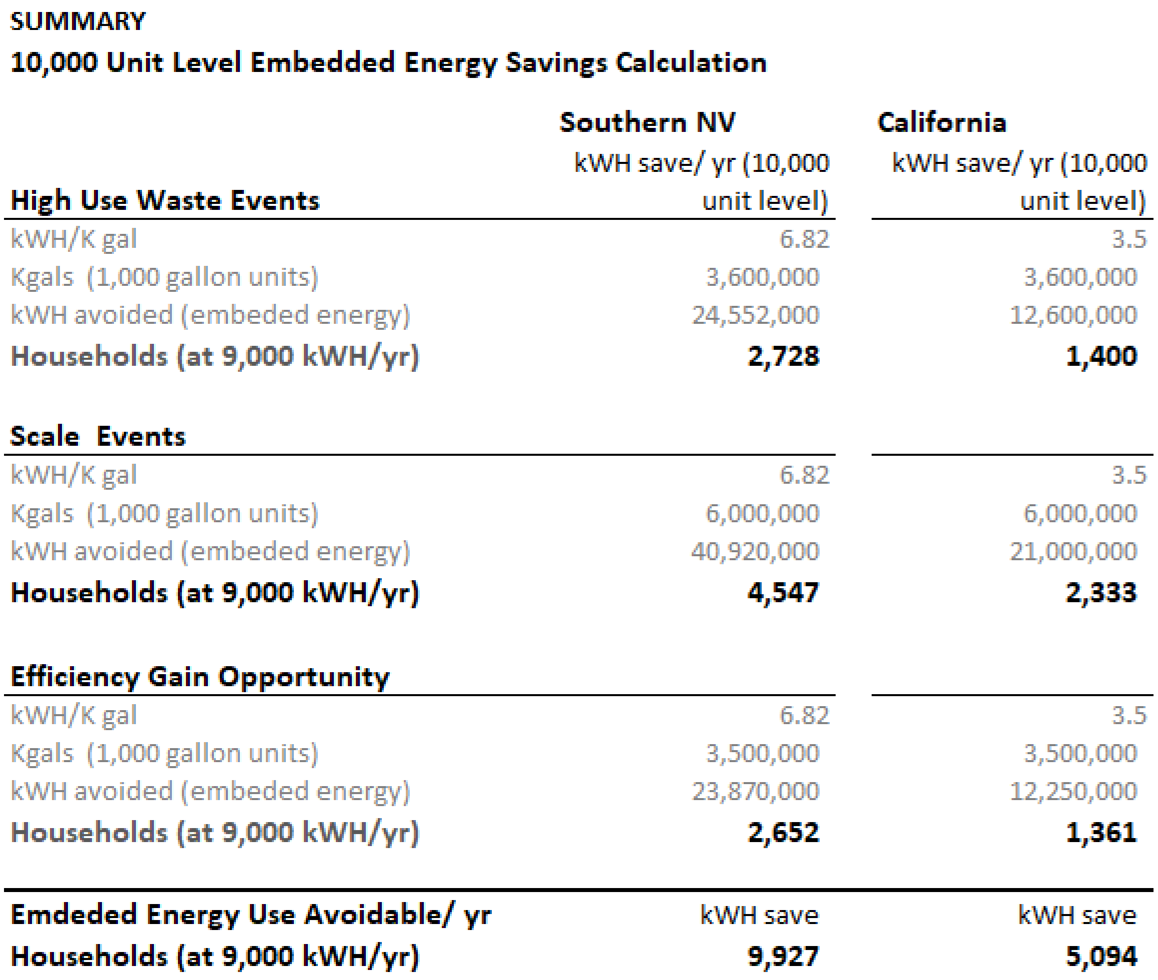
Calculating the same embedded energy savings with the 3.5 kWH/ KGAL cited for California saves enough energy to power 5,000 homes for a year at the 10,000 unit level.



California Embedded Energy Savings Calculation

High Use Waste Events	(67 unit study group)	kWH save/ yr (10,000 unit level)
kWH/K gal in CA 3.5	3.5	3.5
Kgals (1,000 gallon units)	22,000	3,600,000
kWH avoided (embeded ener	77,000	12,600,000
Households (at 9,00 kWH/y	**8.6**	**1,400.0**
Scale Events		
kWH/K gal in CA 3.5	3.5	3.5
Kgals (1,000 gallon units)	36,000	6,000,000
kWH avoided (embeded ener	126,000	21,000,000
Households (at 9,00 kWH/y	**14.0**	**2,333.3**
Efficiency Gain Opportunity		
kWH/K gal in CA 3.5	3.5	3.5
Kgals (1,000 gallon units)	21,000	3,500,000
kWH avoided (embeded ener	73,500	12,250,000
Households (at 9,00 kWH/y	**8.2**	**1,361.1**
TOTAL kWH avoided	**277,375**	**45,850,000**
Households (at 9,00 kWH/yr	**30.8**	**5,094.4**

The potential energy savings at a 10,000 unit level is enough to supply between 5,000 to 9,900 households in a year under the embedded energy scenarios for Southern Nevada and California.



SUMMARY

10,000 Unit Level Embedded Energy Savings Calculation

	Southern NV kWH save/ yr (10,000 unit level)	**California** kWH save/ yr (10,000 unit level)
High Use Waste Events		
kWH/K gal	6.82	3.5
Kgals (1,000 gallon units)	3,600,000	3,600,000
kWH avoided (embeded energy)	24,552,000	12,600,000
Households (at 9,000 kWH/yr)	**2,728**	**1,400**
Scale Events		
kWH/K gal	6.82	3.5
Kgals (1,000 gallon units)	6,000,000	6,000,000
kWH avoided (embeded energy)	40,920,000	21,000,000
Households (at 9,000 kWH/yr)	**4,547**	**2,333**
Efficiency Gain Opportunity		
kWH/K gal	6.82	3.5
Kgals (1,000 gallon units)	3,500,000	3,500,000
kWH avoided (embeded energy)	23,870,000	12,250,000
Households (at 9,000 kWH/yr)	**2,652**	**1,361**
Emdeded Energy Use Avoidable/ yr	kWH save	kWH save
Households (at 9,000 kWH/yr)	**9,927**	**5,094**

The electrical consumption associated with scale events is not included in the embedded energy calculations. It is also significant but at this time, is not converted into kWH or household's worth of savings so it is excluded.

Scale Event Energy Impact is detailed in section 2.3.4 Energy Use Impact of Scale.

3. Event Analysis – Failures, Causes and Impacts Observed

CONTENTS:

This section provides case examples of the different types of failures that have been identified and stopped using data driven cooling tower optimization based on high resolution measurement and automated analytics.

At the start of the study, investigators identified operational and mechanical water waste events as the two categories the known list of issues fell into. In early July 2018 the data showed "control failures" and failures that had multiple underlying causes, "failure chain events", were distinct enough that they needed their own categories.

The following is a breakout of the four categories, the common recurrent failures that make up each category. Failures from any of these categories can cause high water use events or scale events. Since the savings analysis is broken out by high water waste events and scale events, the event case studies are also separated into these two sections.

A powerful finding from the study was the presence of significant waste events across all five types of evaporative cooling units enrolled in the study. Case events for failures observed at HVAC Cooling Towers, swamp coolers, hybrid air/water cooled refrigeration condensers and roof top AC units are at the end of this section.

3.1 Failure Categories Observed in this study

Failures that result in high water waste events or scale events fall into four categories. The categories and the lists of failures observed for each are listed below.

1) Mechanical

A mechanical event is where something breaks. The short list of observations to date includes the following:

- Blow down valves
- Float valves
- Pipes break
- Pumps break
- Failed balance valves

2) Operational

Operational events involve human interaction or admin process errors and are most frequently rooted in miscommunication or misunderstanding but are also observed to include forgetfulness and in very rare cases, negligence. Known operational events incude:

- Poor information flow
- External contractor or non-technical staff error.
- Poor BMP implementation and /or understanding.
- Mistakes
- Administrative disconnects

3) Control Failures

Observed failures that fall in the Control Failure Category include:

- Controller hardware failures
- Calibration failures
- Disinfection lock out failures
- Electrical supply failures
- Plumbing configuration issues that impact sensor performance.
- Sensors being used beyond their normal life span.
- Recirculation pump cavitation induced flow issues.
- Conductivity reading failures caused by
    - failed sensors
    - fowled sensors
    - turbulent flow across a sensor

4) Failure Chain Events

A combination of mechanical, operational and/or control factors that occur at the same time.

These failures are usually complex and hidden.

3.2 Waste Events vs Scale Events

Waste Events result in immediate higher water waste that, once stopped, do not usually have an ongoing continuous impact. Broken valves, pipes, failed controllers, etc. that <u>increase</u> water use are examples. These events, if identified, can typically be stopped quickly.

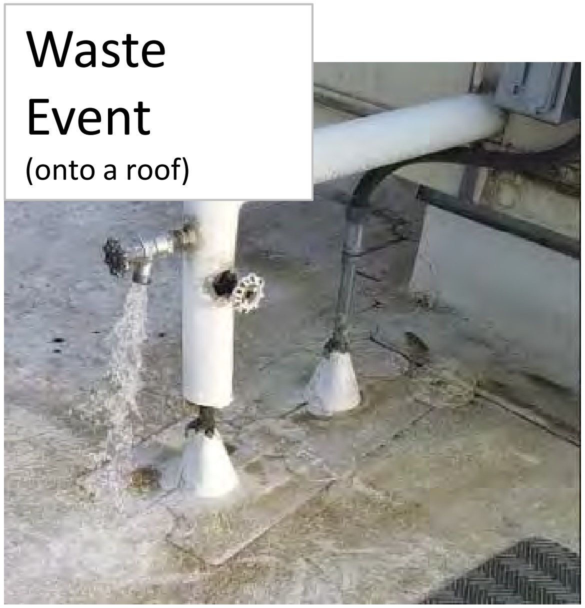
In contrast, if not enough water flows into the unit, a Scale Event happens. If not identified and stopped quickly, scale events result in continuous ongoing waste of water and energy. They reduce the economic life of the unit. Scale events can also damage the refrigerant chemistry, destroy refrigeration compressors and put the refrigerted inventory at risk.

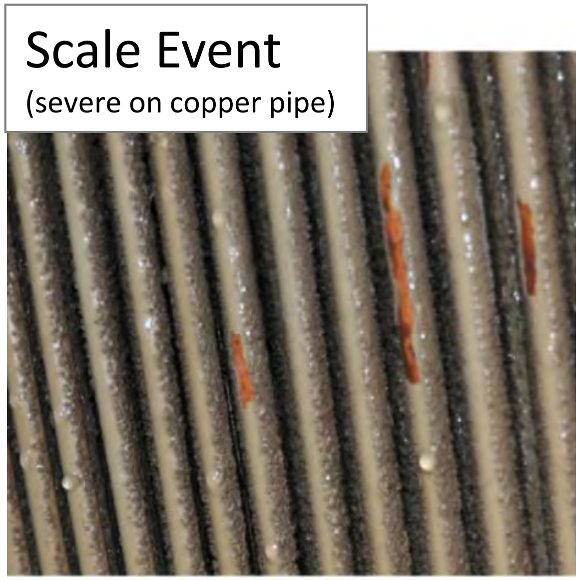
Scale events can happen quickly so they are typically managed as an urgent alarm situation.

Waste events can also have significant impacts but they are typically only wasting water and money and do not typically have the continuous ongoing impacts of scale events. In communities where water scarcity, resilience and sustainability are a concern, waste events can have adverse impacts on the community.

Regardless of whether an event is a scale event or a waste event or what the root cause issue underlying the event is, frequent water use measurement processed in near real time with automated analytics that provide context to the situation makes it possible to identify the issue and stop it quickly.

The next section provides case examples from events that were identified and guided to resolution during the study period.


Waste Event
(onto a roof)


Scale Event
(severe on copper pipe)

3.3 Water Waste Event Examples

Water Waste Events result in immediate higher water waste that, once stopped, do not usually have an ongoing continuous impact. Broken valves, pipes, failed controllers, etc. that <u>increase</u> water use are examples.

These events, if identified, can typically be stopped quickly.

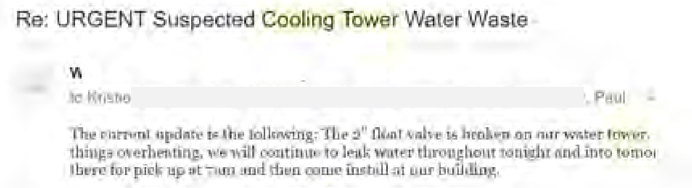
Water Waste Event Example

3.3.1
Broken Float Valve
535,076 gallon event contained

The analytics identified an anomaly in the data around 22:00 on 5 Jun 18. The problem was characterized.

An alert was mapped and sent to site.

Email feedback from location:



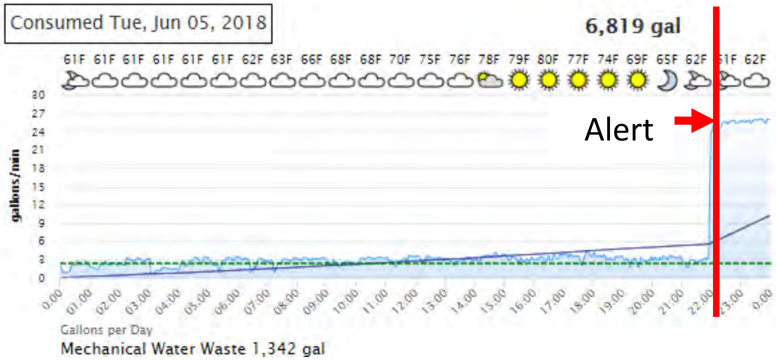
Re: URGENT Suspected Cooling Tower Water Waste

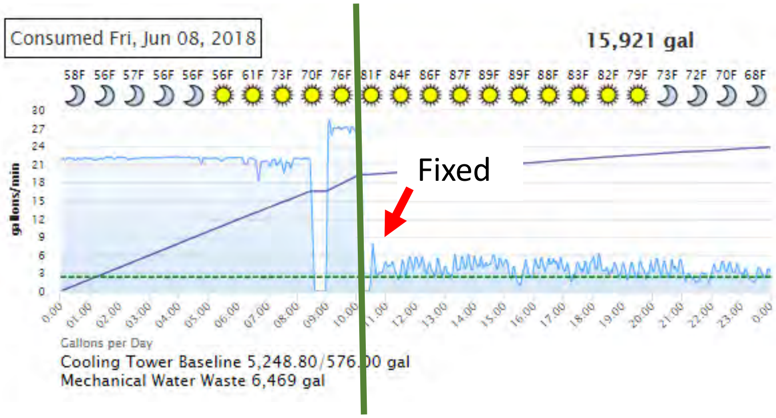
W
to Kristo [redacted] Paul

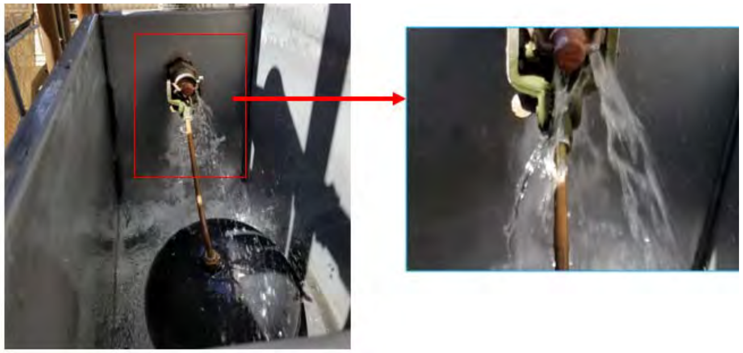
The current update is the following: The 2" float valve is broken on our water tower.
things overheating, we will continue to leak water throughout tonight and into tomo
there for pick up at 7am and then come install at our building.

EMAIL NOTE:

The current update is the following: The 2" float valve is broken on our water tower. While [redacted] has done everything they could do to reduce the water without things overheating, we will continue to leak water throughout tonight and into tomorrow where they will be picking up the new float at LaHabra. They plan on being there for pick up at 7am and then come install at our building.







Water Waste Event Example

Blowdown Failure Event

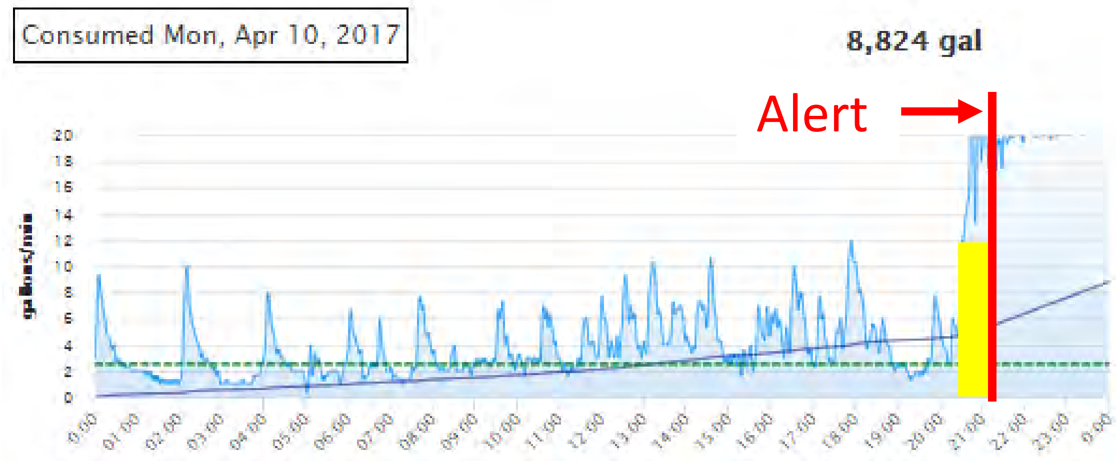
677,015 gallons saved before next scheduled visit.

In this event, the analytics pinpointed the waste event, mapped an alert, and sent it to nontechnical staff on site.

Staff flowed the instructions and then called their service provider to fix the problem.

A blowdown valve failure was fixed by the local expert.

677,015 gallons of water were saved before the next scheduled visit.



Water Waste Event Example

1.75 million gallons per month event
A repair fails and causes a new 1.75 million gallon event.

A first high water waste event was pinpointed in the data at 21:00 on 19Apr 2018. This event was fixed at 13:00 the next day (event A)

Three hours later, a different failure occurred (event B).

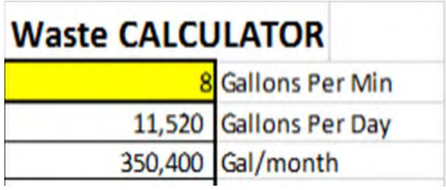
Event "B" was pinpointed in the data and a new alert was set to the location. Data shows that Event B was repaired in about 90 minutes after starting.

Waste event B occurred when the newly installed float valve broke.

The waste volume would have been 1.75 million gallons before the next service visit.

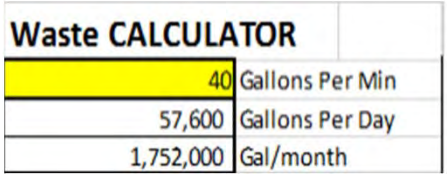
NOTE:
A second failure in the same day can be caused by an initial intervention that did not work properly but they have also been observed to be completely separate events.

Event A)

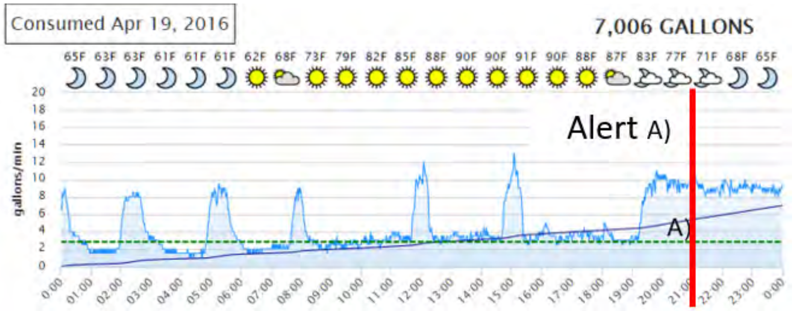


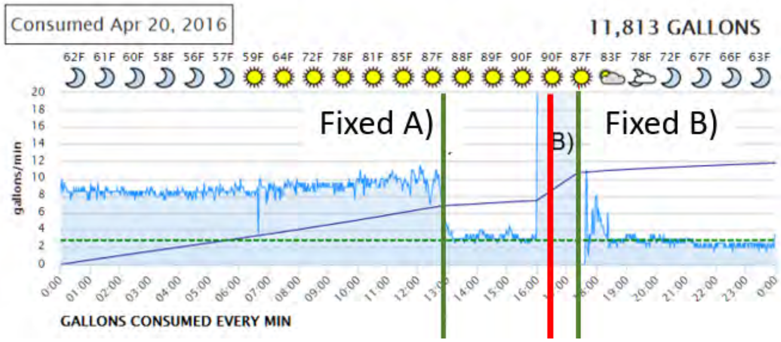
Waste CALCULATOR	
8	Gallons Per Min
11,520	Gallons Per Day
350,400	Gal/month

Event B)



Waste CALCULATOR	
40	Gallons Per Min
57,600	Gallons Per Day
1,752,000	Gal/month





3.3.2 Control Failure Events

Hundreds of examples of what are now clearly understood as “Control Failures” have been detected over the years.

Many of these events have been explained away in spite of the data anomaly being clearly cited as a problem in the data.

Observed failures that fall into the Control Failure Category include:

- Controller hardware failures
- Calibration failures
- Disinfection lock out failures
- Electrical supply failures
- Conductivity reading failures caused by
    - failed sensors
    - fowled sensors
    - turbulent flow across a sensor.
- Plumbing configuration issues that impact sensor performance.
- Sensors being used beyond their normal life span.
- Recirculation pump cavitation induced flow issues.

The following section details how a series of hidden complex failures that occurred at the same time across 4 different locations with 4 different operators initiated a site investigation that finally unraveled the complex combination of failures that is now called “control failures.”

Water Waste Event Example

Control Failure Issues – Diagnosis and Mapping
28 June 2018

Location # 1 - AZ

A waste event was identified May 16. The alert was sent.
An expert operator could not detect the anomaly because the event was not active when they were on site. Things appeared “normal” but data showed the afternoon waste events persisted.

An on site investigation on 26Jun 18 included a research study investigator, the local water quality speciallist, the owner’s staff and the controller manufacture’s senior tech support (via phone).

The manufacture quickly identified a plumbing issue that could create turbulent flow across the sensor. Turbulent flow creates a false reading that would guide the water quality expert to induce a calibration error into the controller unit configuration. The controller manufacture guided the water quality expert on unit calibration details. The plumbing was fixed. The data showed the same failure pattern two days later. Upon a second review, the facility manager found erroneous conductivity readings. The manufacturer was called. Two possible hardware issues were identified. Manufacturer sent new parts for free.

This interaction demonstrates control failures can be complex, hidden and difficult even for experienced technicians to diagnose. Data driven collaboration resulted in mapping out a list of possible failures. This information was immediately applied at 3 other locations. (see Location 2, 3, and 4 case examples in following pages).

Savings at this location:
60,000 gal/month.
720,000 gal/ year.

Water Waste Event Example

Controller Failure

Location # 2 – AZ

Start: 2 April 2018
End: 5 July 2018

As with many control failure issues, the root cause issue was initially mistaken for a water quality change. The volume and pattern of the recurrent events indicated something else was wrong.

The local expert operator traced out and found a 24v power supply contact had a loose fitting and caused intermittent waste. The issue was fixed.

NOTE: using an electrical meter to trace out a 24v power issue inside of a controller is complex. In addition to understanding electrical issues, the expert operator needed to understand plumbing and also have sufficient competence regarding a range of water quality management issues. The need for familiarity across a few different trades makes local expert operators an important part of the solution set.

Savings:
1,500 gal/day *30 days
= 45,000 gallons/month

Water Waste Event Example

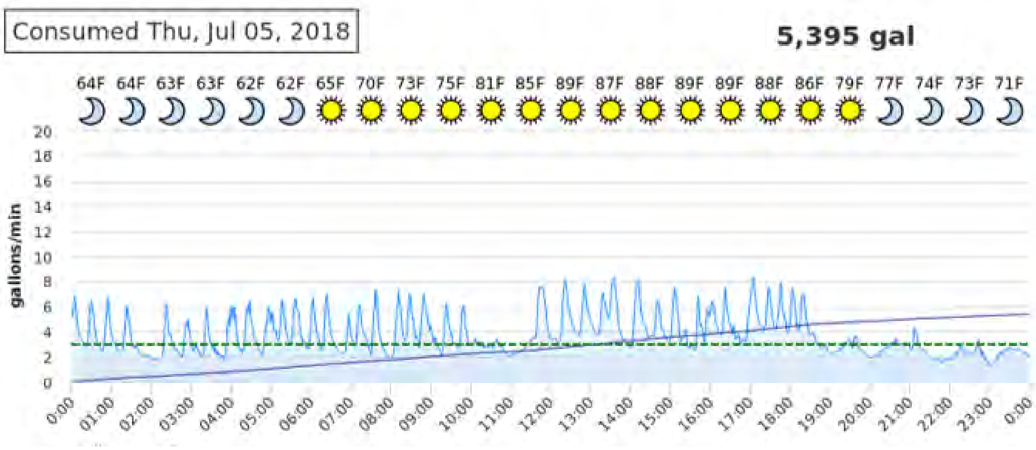
Control Failure

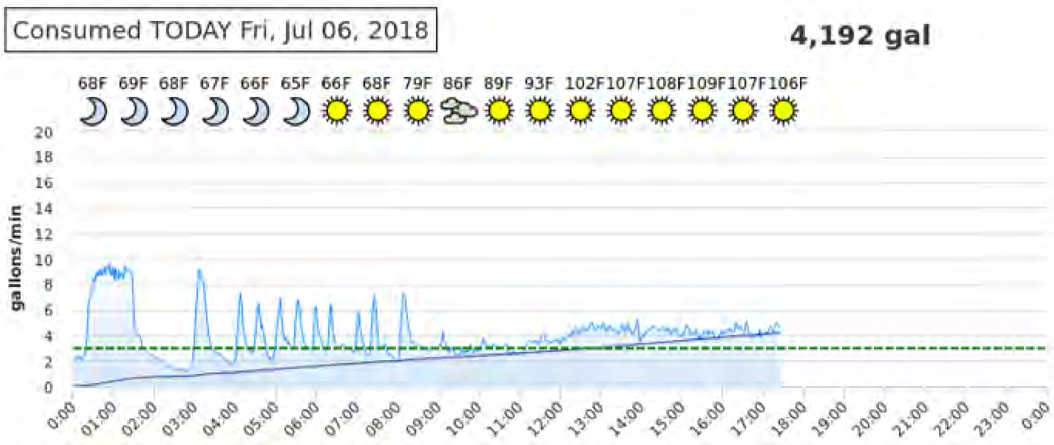
Location # 3 – CA

Similar to locations #1 and #2, multiple signatures of a control failure were observed in the minute resolution measurements from this location.

The signatures are subtle but were sufficient to guide the local experts on what to look for.

An email with updated guidance was sent to the local expert and an hidden control issue was discovered and fixed.





The information in this chart is for internal APANA use only.

Water Waste Event Example

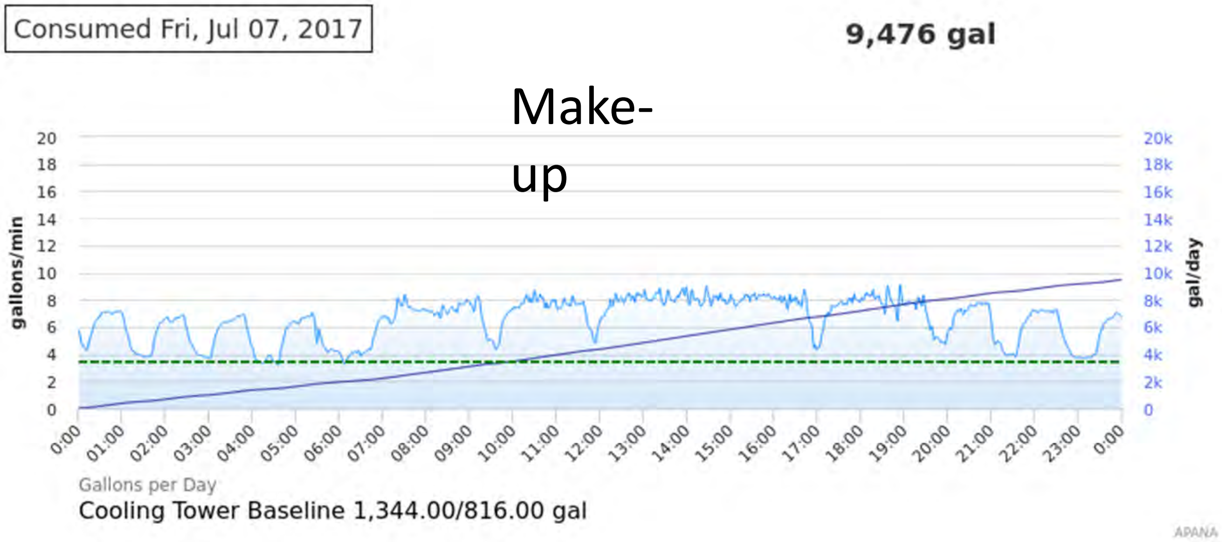
Control Failure
Location # 4 – AZ

In this event, the unit was “told” to blowdown continuously for extended periods of time. The 250 gallon sump was washed out 10 times over the course of 12 hours.

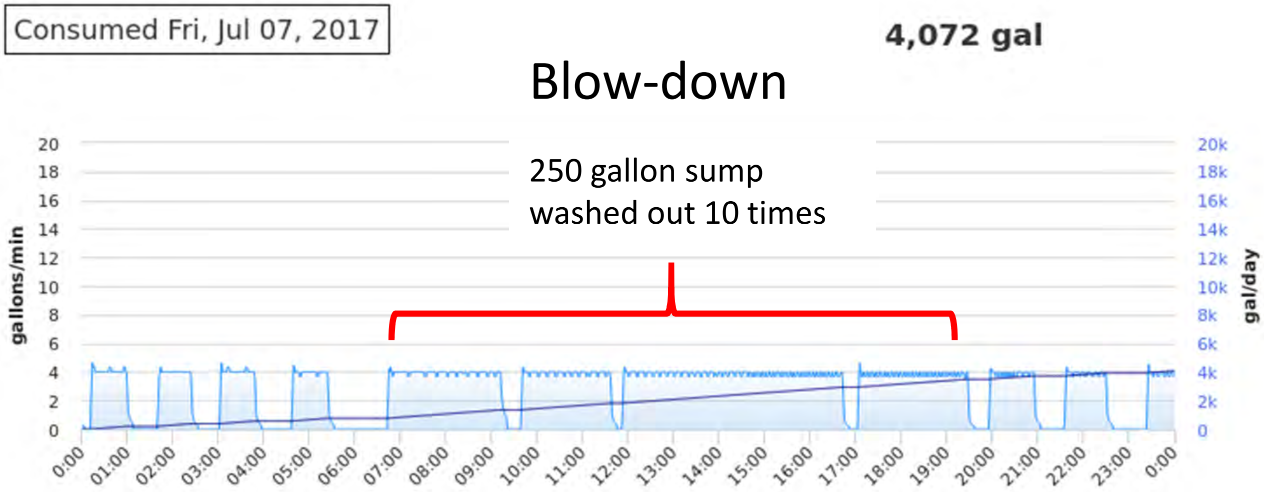
The location was sent an alert with guidance.

The issues was fixed.

2-3,000 gallons wasted per event saved.



Make-up



Blow-down

250 gallon sump
washed out 10 times

Water Waste Event Example

3.3.3 Failure Chain Events

Failure chain events are distinct from specific, isolated mechanical, operational or control events because they are characterized by a failures in two or more areas. These types of events have been observed to create confusion that leads to inappropriate interventions.

Since failure chain events can last for extended periods of time, understanding how to pinpoint them and guide local experts to resolve the root cause issues has significant potential for saving water.

The unraveling of the factors involved in fail chain events is an example of the insights that can be gained when measurement happens at a frequent enough interval to reveal details that lead to an accurate diagnostic review. When the diagnosis is correct, the prescriptive guidance can be automated.

In the following two examples, measurement pinpointed the existence of a problem. A metadata analysis helped narrow in on what the likely issues were and where to look.

Given the data and case examples for failure chain events, it is reasonable to assume that at a 10,000 unit level, billions of gallons of water could be saved by identifying and resolving these types of events right when they happen.

1) Mechanical

2) Operational

+ 3) Control failures

---

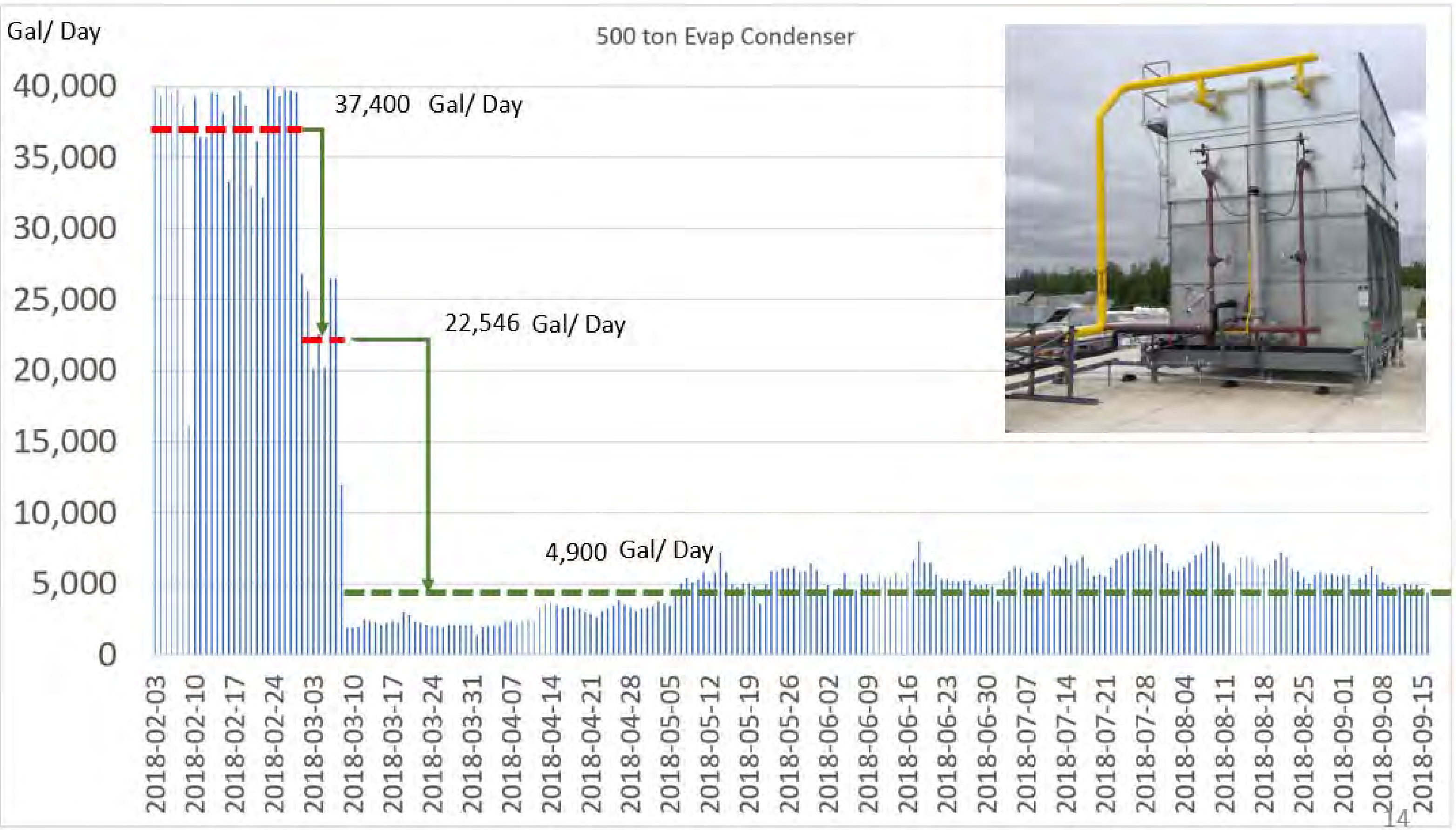
4) Failure Chain Events

(combination of factors)

Water Waste Event Example

Failure Chain Event: Mechanical + Operational
11.8 million gal/year waste

At start-up, the water use fingerprint showed high continuous use that was significantly greater than similar applications in other areas. A site review found an overflow valve that was not properly set. The staff, operator and contractor were aware of the situation. Measurement, reporting and best management practice guidance is saving 11.8 MGY. This was the largest single waste event observed at an evaporative condenser unit over the current phase of this study.



Water Waste Event Example

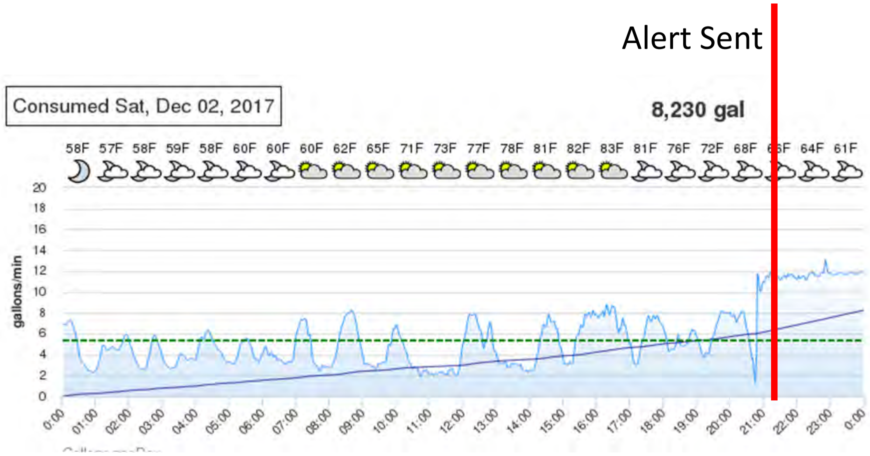
Failure Chain Event: Mechanical + Operational failure
3.6 million gal/year waste level

In this case, a technician from a different trade was operating the unit. After receiving an alert, he repaired a broken float valve and believed everything was fine.

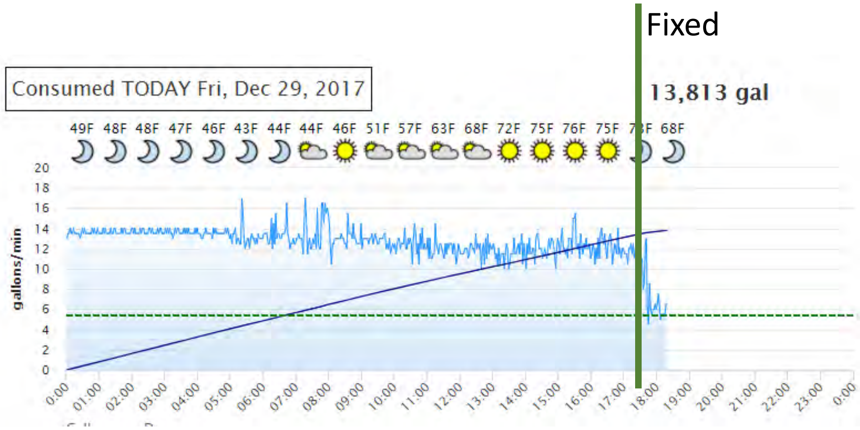
The measurements indicated there was still a problem. The service provider returned to site three times. Each time, the service provider insisted the unit was operating correctly.

On 29 December 2017, support staff guided the tech on a 10 min review via cell phone. A failed balance valve was discovered. This is a hidden and rare failure but, the data pinpointed it shortly after it started on 2 December at 21:00 hours.

The rarity of the mechanical failure, combined with a service technician who is not a cooling tower expert, resulted in this failure running far longer than necessary. Given the service provider's confidence, this unit would have wasted water for months if not years.



Alert Sent



Fixed

Scale Events

3.4 Scale Event Failures

This section provides a review of the root causes, the impact of scale build-up, and some event examples necessary to provide context.

Minerals build up on the heat transfer surfaces when one or more failures go undetected long enough for the concentrations to exceed the Max COC levels. If no one sees an obstructed blowdown valve or a broken pipe, damage escalates quickly. When someone forgets to plug a piece of equipment back in after they used the outlet to charge their cell phone, damage escalates quickly. If one of a list of documented control failures happens, the damage escalates quickly. Owners and operators are blindsided when scale events occur.

In 2017, investigators were able to interact with local staff on 37 events where the data feed identified and guided quick resolution to the active scaling event. Hundreds of other event notifications were issued where events stopped but there was no local feedback.

The following provides a summary of the failures that cause scale events and case examples to show how frequent measurement pinpoints the start of damaging scale events and guides interventions that stop the events before damage occurs.

Scale Events

Causes of Scale Events

Since 2015, collaboration with expert operators across study sites has allowed researchers to map out a list of different root cause failures that lead to scale events.

Understanding what causes scale events is a significant finding. Scale events are the most damaging events and are the reason water quality operators run COC lower than what best management practices suggest is possible.

The failures observed in the study population are not avoided by operating at lower efficiency. They are distinct events and they stand out when measurements are frequent and processed in near real time.

Observed Causes of Scale Events

Obstructed blowdown valves

Pump Failures

Operator Errors

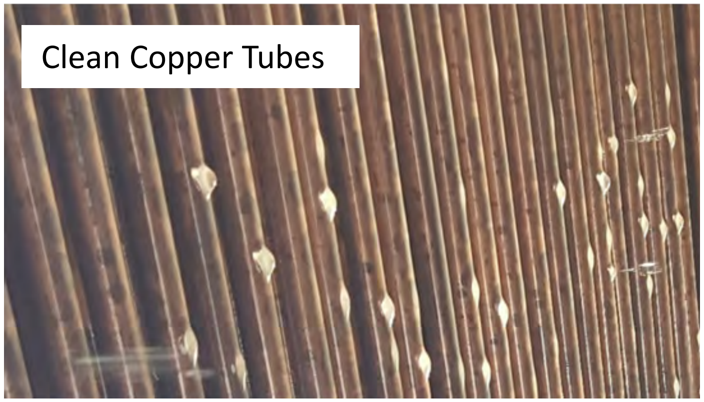
Outside Contractor Error (unplugging equipment)

Plumber Error (depriving evap unit of water)

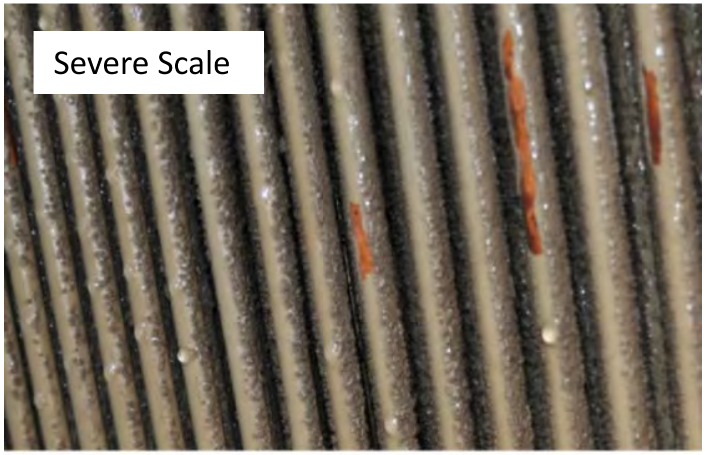
Pipe breaks/ location supply interruptions

Control Failure(s)

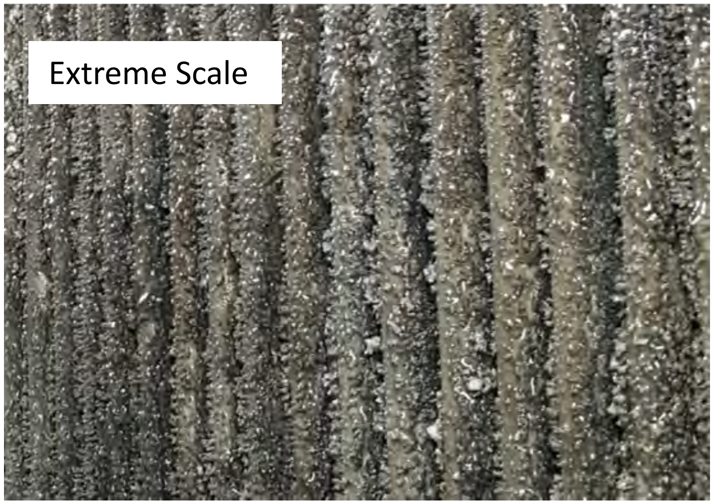
- Failed controller hardware
- Failed electrical supply
- Calibration offset issues
- Sensor read issues
- Stuck disinfection lock out



Clean Copper Tubes



Severe Scale



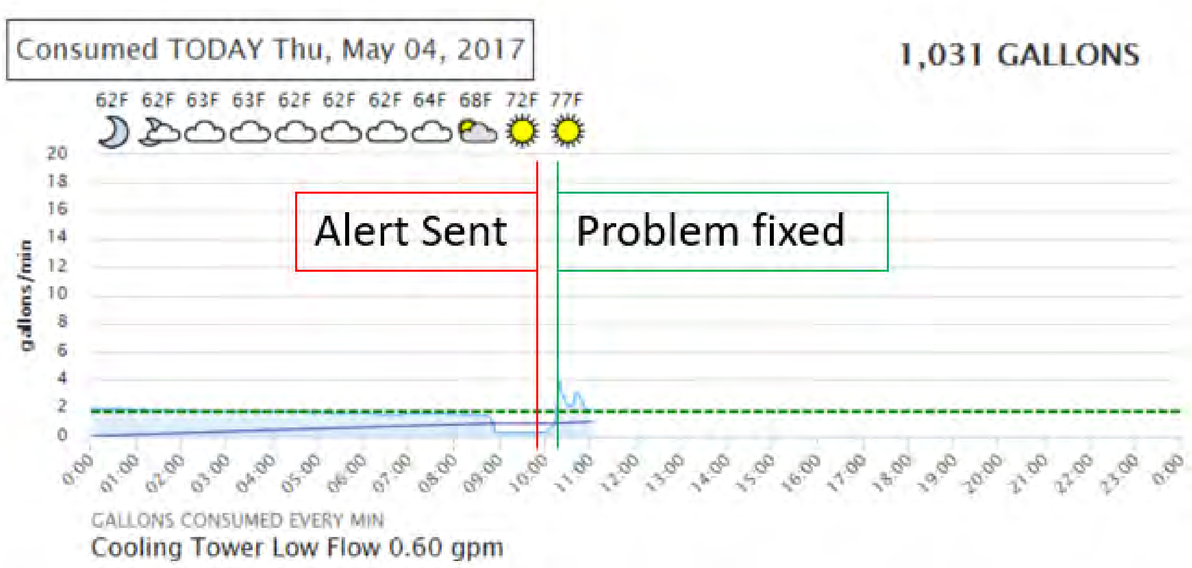
Extreme Scale

Obstructed Blowdown Valve
Scale Event Avoided

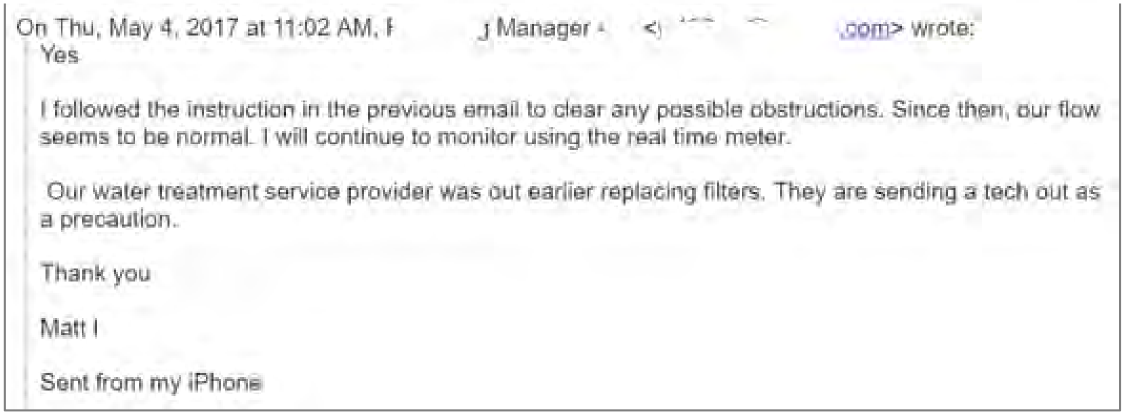
Scale Events

In this example, the location staff received the alert, followed instructions, and stopped the sale event quickly. For most events, busy site staff do not provide detail on what they did and the result. In this case, the email documentation is significant because it demonstrates that the non-technical recipient followed the instructions and fixed the problem.

This event would have caused severe scaling over the month it would have otherwise run.



Email from location manager



On Thu, May 4, 2017 at 11:02 AM, F[redacted]g Manager [redacted] <[redacted].com> wrote:

Yes

I followed the instruction in the previous email to clear any possible obstructions. Since then, our flow seems to be normal. I will continue to monitor using the real time meter.

Our water treatment service provider was out earlier replacing filters. They are sending a tech out as a precaution.

Thank you

Matt I[redacted]

Sent from my iPhone

Scale Events

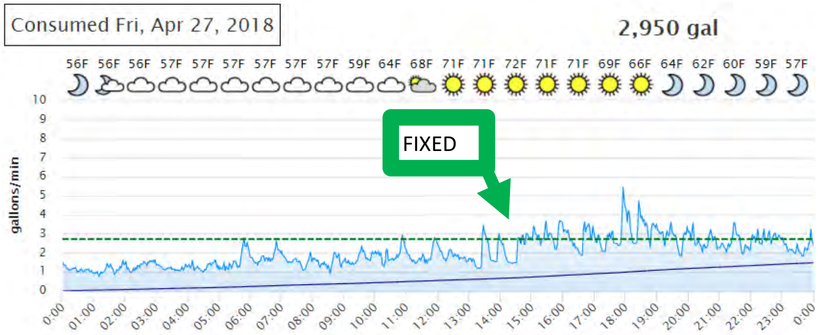
Outside Contractor unplugged equipment
Scale Event Avoided

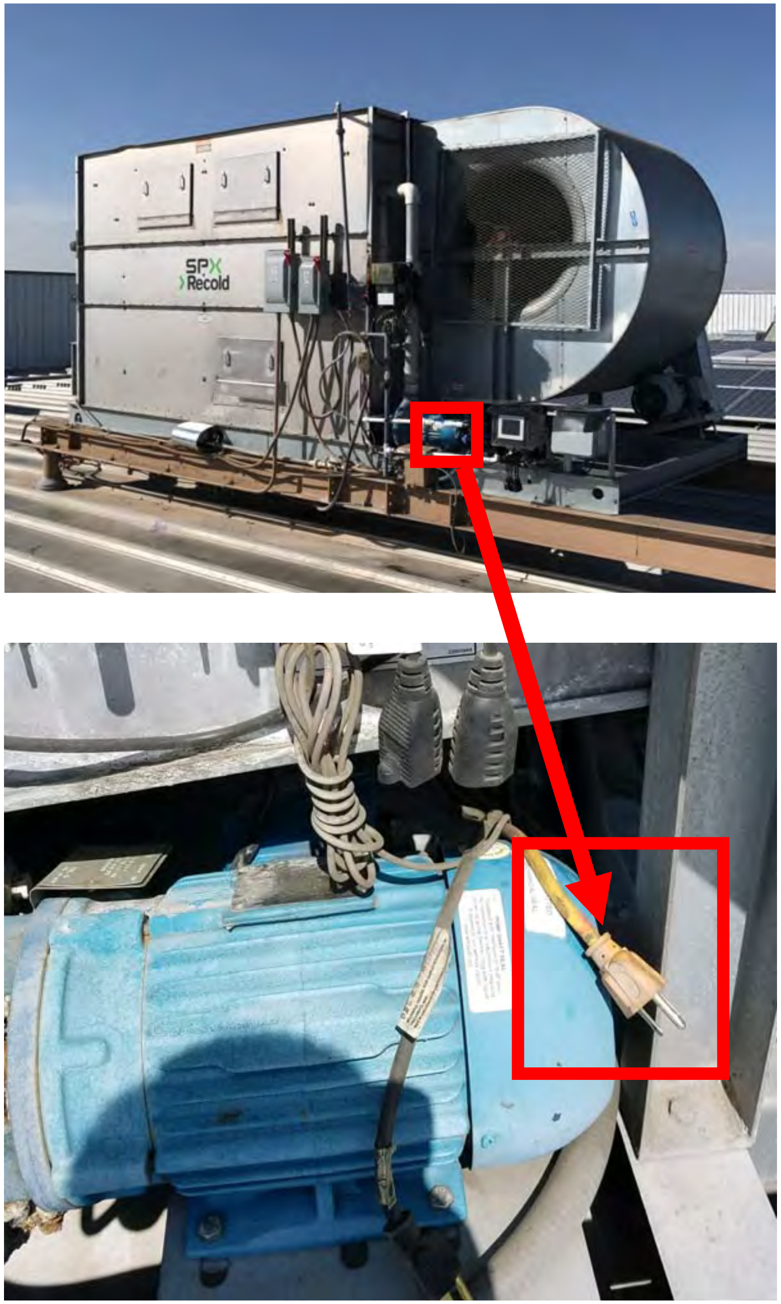
An alert advising immediate visit by a water quality expert was sent to the customer, corporate, and the local technician. Technician was dispatched immediately.

Here is what was found:

> **Note from service company 27 April 2018**
> …our tech found that the bleed solenoid and inhibitor pump were unplugged from the controller.
>
> Not sure why someone would have done this.
> Picture attached.

This would have run unnoticed until the next service visit (4 weeks). This unit would have suffered severe scaling.





Scale Events

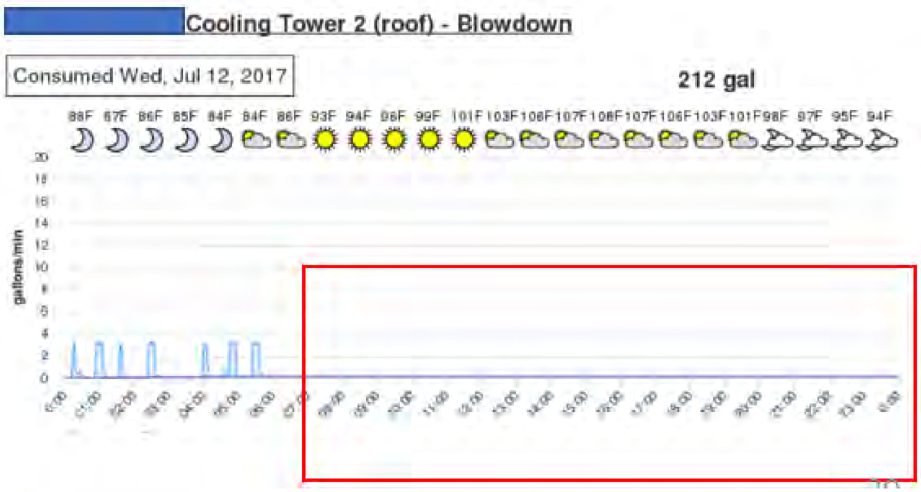
Operator Error
Scale Event Avoided

For this event, the refrigeration contractor called to provide feedback on the event. This was a human error that can happen anywhere. It was caught and fixed quickly.

Event Note:

"13Jul17: [redacted] from [redacted] called to say Water Treatment Tech was out yesterday and forgot to turn the valve back on after taking a sample from the conductivity probe. It's back on now."

SAVINGS:
Average daily water use is 4,669 gallons of water. It is reasonable to assume this unit would have scaled up significantly. Water, chemical and energy use would increased in the 30% to 70% range for the remainder of the life of the unit.



Blowdown Control Failure
Scale Event Avoided

SITUATION

Anomalous flow detected and pinpointed as a high risk scale event. An alert was sent to site staff.

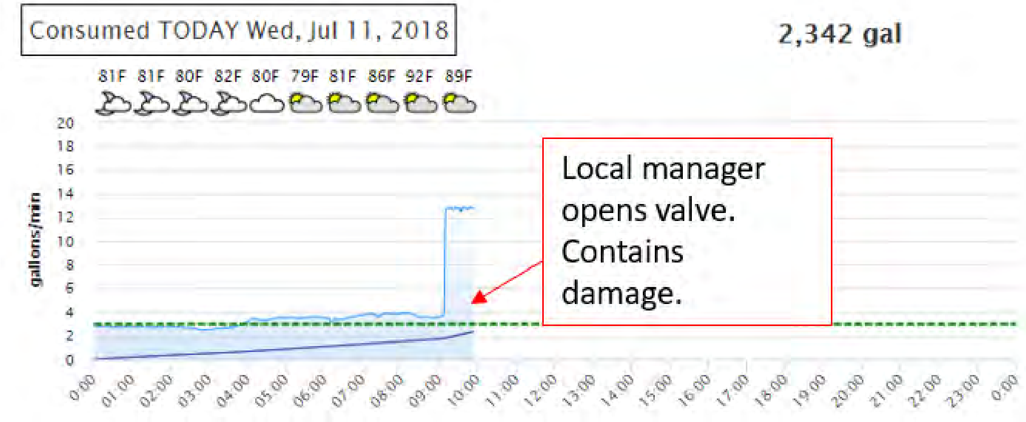
26 hours later, a local manager responded to the alert. By this time, minerals had concentrated beyond safe limits and started to deposit on the hot copper coils. The conductivity had risen from around 3,000 to 11,800 in the 26 hours without blowdown.

ACTION: Location manager was guided to open the valve and flood the unit with water to wash out the high mineral content water in the sump.

The location called their service provider to follow-up on the issue.

RESULT:

Conductivity dropped from 11,850 to normal 3,000 range. The scale event stopped.



Local manager opens valve. Contains damage.

NOTE:

Conductivity rose from 3,000 to 11,800 in 26 hours. Conductivities above 5,000 in an evaporative condenser indicate high mineral concentrations and active scaling events.

This case example demonstrates scale events can become severe quickly.

Scale Events

Plumber Error
Scale Event Avoided

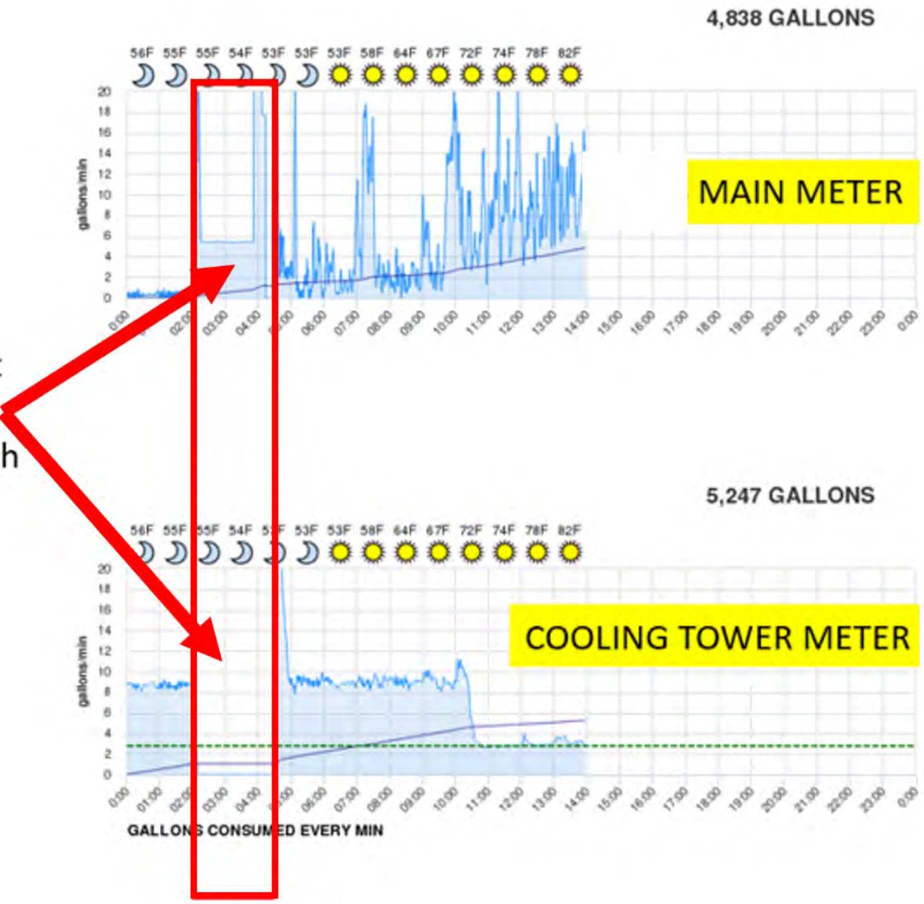
Event Note:

Cooling tower makeup water stops for 2.5 hours each night because the plumber set up the new water softener to stop water flow to the building during softener regeneration.

The situation was discovered in two days by comparing the cooling tower water flow to the main building water use.

During the nightly "scale" events, the

a) copper scaled up.
b) Refrigerant heated up and has likely changed chemically.
c) Compressor wear and tear increased.
d) Inventory was put at risk.



Exact Time Match

Scale Events

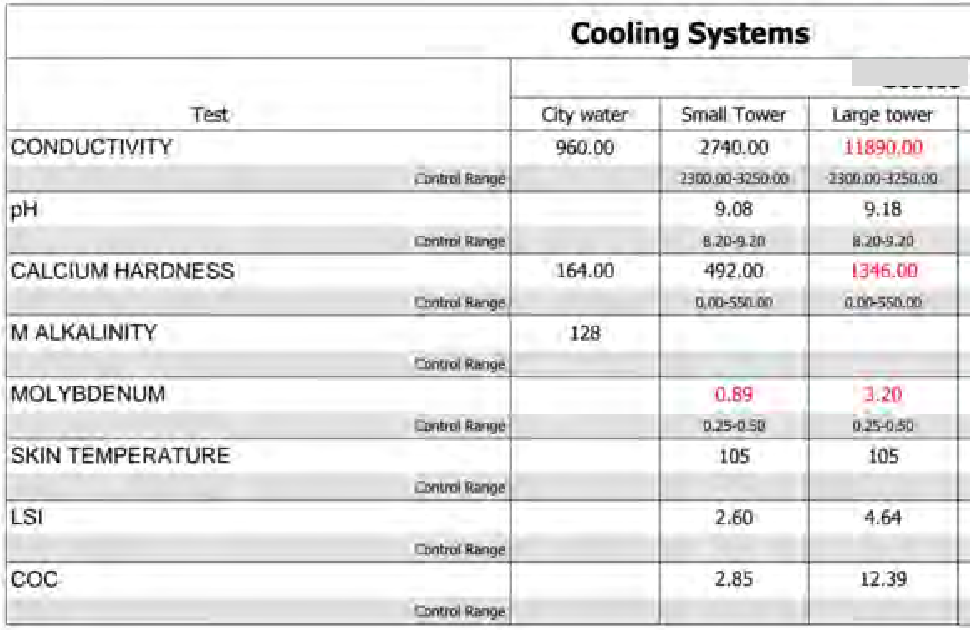
Blowdown Valve stuck closed

Severe Scale Event documented in the operator's monthly visit report.

A review of 2,477 monthly service visit reports found documentation of numerous severe scale events.

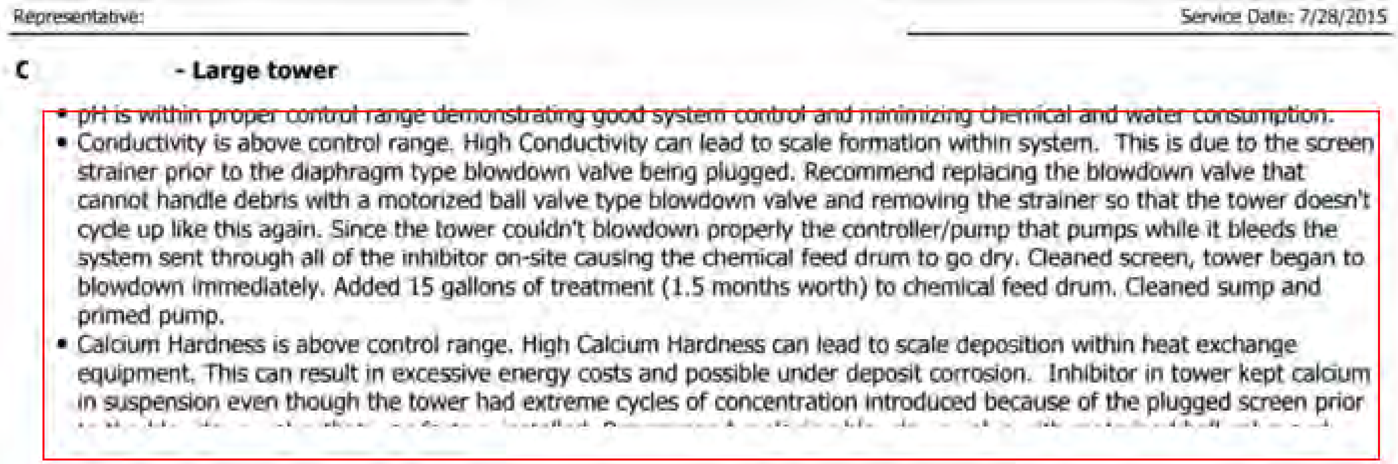
In the table to the right, the tower conductivity is 11,890. Ca Hard is 1,346. The LSI is 4.46. Each of these test results indicates a severe scale event was discovered too late.

This is one example of 169 scale events documented in the 2,477 service provider reports analyzed.



Cooling Systems

Test	City water	Small Tower	Large tower
CONDUCTIVITY	960.00	2740.00	11890.00
Control Range		2300.00-3250.00	2300.00-3250.00
pH		9.08	9.18
Control Range		8.20-9.20	8.20-9.20
CALCIUM HARDNESS	164.00	492.00	1346.00
Control Range		0.00-550.00	0.00-550.00
M ALKALINITY	128		
Control Range			
MOLYBDENUM		0.89	3.20
Control Range		0.25-0.50	0.25-0.50
SKIN TEMPERATURE		105	105
Control Range			
LSI		2.60	4.64
Control Range			
COC		2.85	12.39
Control Range			



Representative:

Service Date: 7/28/2015

C - Large tower

- pH is within proper control range demonstrating good system control and minimizing chemical and water consumption.
- Conductivity is above control range. High Conductivity can lead to scale formation within system. This is due to the screen strainer prior to the diaphragm type blowdown valve being plugged. Recommend replacing the blowdown valve that cannot handle debris with a motorized ball valve type blowdown valve and removing the strainer so that the tower doesn't cycle up like this again. Since the tower couldn't blowdown properly the controller/pump that pumps while it bleeds the system sent through all of the inhibitor on-site causing the chemical feed drum to go dry. Cleaned screen, tower began to blowdown immediately. Added 15 gallons of treatment (1.5 months worth) to chemical feed drum. Cleaned sump and primed pump.
- Calcium Hardness is above control range. High Calcium Hardness can lead to scale deposition within heat exchange equipment. This can result in excessive energy costs and possible under deposit corrosion. Inhibitor in tower kept calcium in suspension even though the tower had extreme cycles of concentration introduced because of the plugged screen prior

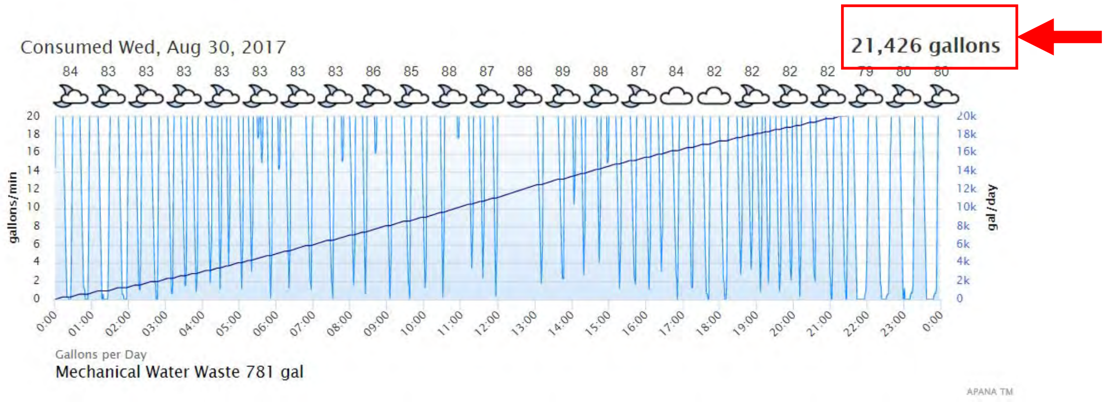
Plugged screen filter prior to blowdown valve

Small amount of debris that passed screen filter that caused valve to stick closed.

3.5 Malfunctions Detected in Other Unit Types

- 3.5.1 HVAC Cooling Towers
- 3.5.2 Water Cooled Roof Top AC Units (RTU’s)
- 3.5.3 Swamp Coolers
- 3.5.4 Hybrid Refrigeration Condensers (air/water cooled)

3.5.1 HVAC Cooling Tower Example

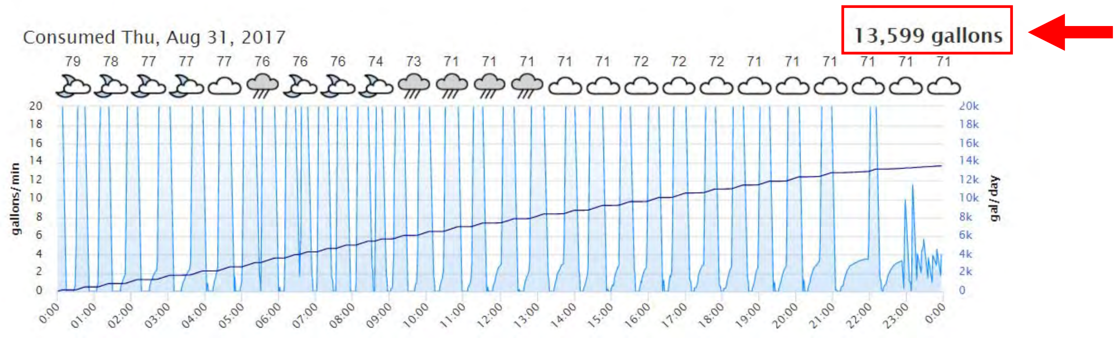


Wasteful operational practice was guided to efficiency though measurement and comparison to other locations.

10,000 GPD Saved

1.8 Million Gal/yr

Annual:
3,650,000/2= 1.8 million



3.5.2 Water Cooled Roof Top AC Unit (RTU) failure

2,700,000 gallons saved in a month

As the name suggests, roof top AC units are on the roof. They receive infrequent reviews. As with everything else that is connected to water, they have failure points that can cause million gallon+ water waste events. This specific event was induced by a plumbing contractor who made a mistake.

The contractor mistakenly turned on the water supply to the roof top units. ALL the units were open for winter. Water flowed at 65 gallons per min across the roof into the storm drain.

Analytics pinpointed a problem and sent an alert. Given the severity of the event, the location was called. Since the water was running into the drain, the location manager had now way to know.

Feedback from the location manager provides insight into how common it is to assume things work and how surprising it is when significant events are discovered.

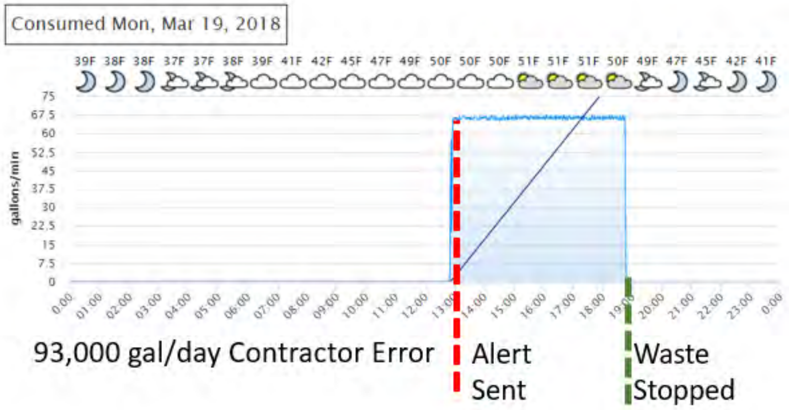
“they were just here, everything is fine”

Location Manager, 13:35

Problem fixed. 19:00

“this would have run all month”

Location Manager, 19:20



93,000 gal/day Contractor Error

Alert Sent

Waste Stopped

3.5.3 Swamp Cooler failure

1 million Gal/yr Waste

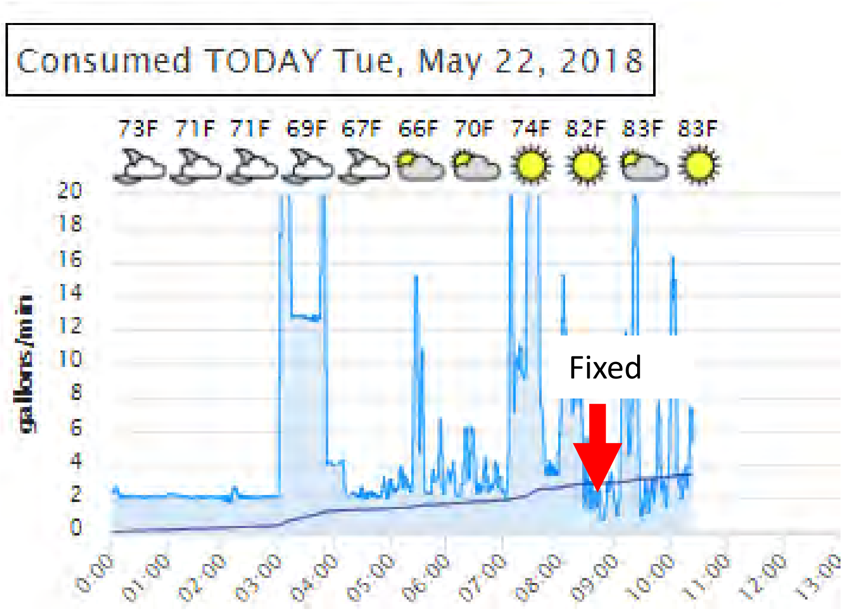
Location staff implemented the alert’s review instructions perfectly but could not find the issue.

A service provider was hired to perform a review. Research investigators supported the local technician with real time data and guidance.

A swamp cooler hidden on an inaccessible roof had a float valve failure.

This location has an evaporative condenser and is a busy site so the increased use would not have stood out in a water bill. Given the location of the swamp cooler, this event would likely not have been noticed.

2,800 Gal/day
Swamp Cooler Failure



3.5.4 Air/ Water Hybrid Condenser Failure

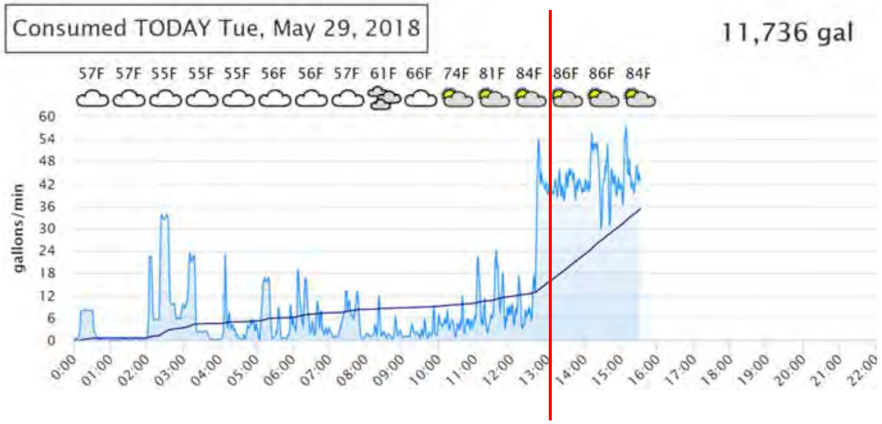
1.5 million gallon/ month waste event stopped

Air/water hybrid refrigeration condensers use water when the outside temp exceeds a set limit- typically 75-80 degrees.

Under normal circumstances, these units use far less water than a typical evaporative condenser.

If they have a failure, the waste can easily exceed a million gallons because most of the water waste runs into a drain so it is not seen. Also, these units are not serviced on a routine basis so events can run for months or years.

With monitoring, these units can result in significant water savings. More study is recommended.



35 gpm waste event

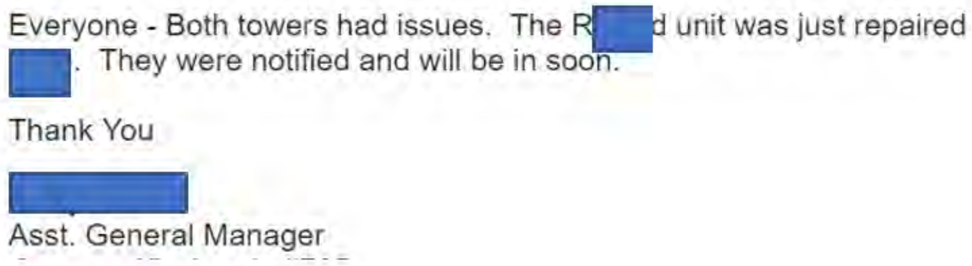
1.5 million gallons per month.

3.5.4 cont. Hybrid Condenser Failure

EVENT: 8,600 gpd. 259,000 month, 3.1 million/yr.

In this case example, two different types of hybrid refrigeration condenser had a failures at the same time. The email from the Asst Manager provides context for this event.

Email from Site:

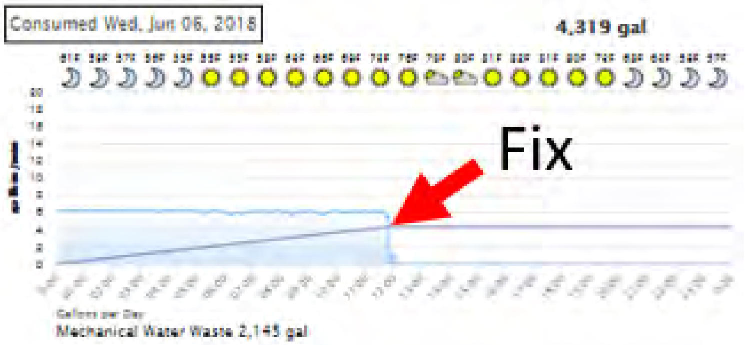


Everyone - Both towers had issues. The R[redacted]d unit was just repaired [redacted]. They were notified and will be in soon.

Thank You

[redacted]

Asst. General Manager



Mechanical Water Waste 2,145 gal

4. Study Changes and Complications

Efficiency Score – Does a fair, data driven KPI drive change?

Although there are many case examples where technical conversations based on the data stopped waste and asset destruction, there is localized documentation of resistance to adopting best management practice standards that some expert operators use routinely.

Investigators had to postpone the goal of influencing some locations into efficient operation when resistance to change risked becoming a conflict. Operating at predetermined COC regardless of the chemistry of the makeup water can be a strongly held belief when it has been the routine for many years.

The "Efficiency Score" KPI was conceived to address this type off resistance. Its development and testing was delayed as work on identifying how to reconcile feedback regarding possible Max COC by units moved forward. With a fair, practical approach to determining Max COC, or at least structuring the conversation so it is based on measurements and expert operator insights, the power of a KPI and reporting can be studied as future generations of this research unfold.

Control Group Participation

The original study design was to enroll 10 units with only monitoring and no interaction. The owners participating in this study had seen results at other units. They had participated in the use of data and technical collaboration and due to their experience, wanted active monitoring added to all their remaining units. They declined the offer to have 10 units participate in the control group.

Case examples where problems were identified and guided to resolution outside of the traditional operational routines do serve as insight into what would happen if data and collaborative guidance were not available.

The lack of a pure control group is something that may be possible to overcome in future versions of this research. The design should consider figuring out how to obtain owner approval and possibly an IRB opinion on what to do when active high waste or asset destruction events are observed in the control group.

Threshold Limit Consensus and a Fair Path to Potential Max COC

The study time line was extended to allow for further discussion with local operators before launching the comparison reporting and status ranking the study design proposes as a "data driven" management tool to narrow the range of operation preference to an optimal level while encouraging elimination of operational "drift." This issue became contentious with some operators while other expert operators were observed to be managing multiple units in compliance proposed standards.

Understanding what could be cited as “efficient” and how to assess the multiple factors involved opened the path forward for the outcome testing this part of the study had originally hoped to deliver. Given the wide range of efficiencies documented as part of this study, actively testing and refining reporting and guidance methods aimed at driving behavior that produces efficient outcomes appears valuable now and into the future.

KPI Name Change

After receiving feedback from operators, data scientists and experts in the field we realized there was confusion regarding the term % Optimized. The study term “% Optimized” was changed to “Efficiency Score.”

The use of the term “efficiency” appears to meet the study goals and provide a more immediately understood perspective of the information behind the term.

The word “score” is also easy to understand, and it has the value of being relatable to the management term “score card” as well as setting the KPI up for use in a game environment.

This is a nomenclature change only. Everything surrounding the original concept and the process of establishing criteria that enables comparison across units and geographies remains the same.

5. Conclusions and Recommendations

For cities facing scarcity, growth constraints, or seeking to improve resilience, this study shows an effective way to build capacity by controlling water and energy waste in evaporative cooling systems beyond the city meter.

The problems that cause water and energy waste are split into two distinct areas that, although interdependent, require different tool sets to address.

Problem Set # 1

The need to pinpoint waste and scale events and fix them quickly.

Problem Set # 2

The need to operate efficiently everywhere

(close to Max COC)

For problem set #1, this study reviewed and validated a real-world example of a CII focused Smart City Water Management approach by applying technology previously deployed in landscape irrigation and building water management applications to test effectiveness in evaporative cooling units. This study's findings demonstrated that:

a) Real-time measurement of water use enables analytics software to quickly identify failures that cause waste and can lead to asset damage.

b) Actionable information, delivered to non-technical staff, in relatively real-time, is effective at guiding timely resolution of detected problems.

c) The engagement enabled by real-time measurement with actionable information produces immediate savings and builds knowledge to expand savings across the built environment.

For decision makers, knowing the failure points for different end use categories and where to put effort could improve decision making and incentive program outcomes.

Recommendations

1. Include high-resolution measurement and real-time problem-solving in water conservation incentive programs to achieve savings, improvement in decision making and outcomes.
2. The energy savings discovered by this study suggests a collaborative effort of water providers with electricity providers could enhance cost effectiveness of large-scale programs to implement the methods used in the study.
3. Implement a larger scale demonstration at a Smart City CII level.

Specific to evaporative condenser water use, the data shows that identifying and eliminating "scale events" is the single most impactful way to optimize water and energy use in evaporative condenser units. Savings come from three areas:

1) Avoiding the future increase in water and energy use after a scale event happens.
2) The same "security system approach" used to identify and control scale events simultaneously identifies and guides intervention for high use water waste events.
3) Fear of scale is why many units are operated at actual COC levels that are much lower than the potential Max COC levels for a specific unit.

This research study shows that severe scale events occur because of mechanical, operational or control failures that are not stopped before damage occurs. A focus on identifying and stopping scale events addresses the root cause issue for inefficient operation, as well as energy and water waste associated with high water waste and scale events.

As a CII conservation infrastructure, near real time measurement and analysis shows the potential to transform water conservation activities, so they are not only more effective, but provide deeper value and meaningful engagement with end customers and the technical service providers who influence outcomes.

Specific to problem set #2, the challenge of ensuring efficient water and energy use from an operational constraint perspective requires on site water test and interaction with expert water quality specialists. Although this is informed by the continuous measurement used for problem set #1, it requires standardization and different tools to work effectively at a built environment level.

Agreement on how to establish what efficiency is from a Max COC level by specific unit, and easy ways to facilitate the data capture from expert water quality specialists during their service visits, are important first steps. Normalizing the results so a fair comparison of efficiency can be made across all units is dependent on the first two steps. The fair comparison provides a path to standardized implementation and reporting of routines that result in efficient operation.

Efficient operation is when water is reused to the point the maximum potential number of cycles of concentration for the specific unit is reached but <u>not</u> exceeded. A Max COC determined by a reaching a threshold concentration of a limiting variable, an LSI limit and/ or a unique unit specific constraint that is documented by an expert operator in a form that can be evaluated considering known best management practices (auditable), allows a fair evaluation of whether a unit is operated efficiently or not.

A web application developed with feedback from a wide range of operators shows promise to provide a practical way to collect the onsite test results and insights needed to automate the calculation of Max COC based on LSI and other limiting thresholds. The automation of this step helps operators, but it also provides a practical way to deploy a standardized, auditable path to establishing a Max COC for a specific unit. A fair, auditable Max COC target creates a path toward a fair, uniform key performance indicator (KPI). A KPI allows for comparison of efficiency across applications, geographies, and equipment types. Current working name for this KPI is "Efficiency Score."

Recommendations for problem set #2:

1) Define Max COC for a specific unit's service visit as: Cycling the water use to the point that at least one limiting variable is met, but not exceeded.
2) Automate the collection and analysis of on-site water quality test data and insights from water quality specialist.
3) Use a standardized Key Performance Indicator to normalize reporting outcomes.
4) Make efficiency a game - Use reward and recognition tools to encourage optimal KPI outcomes as well as engagement and sharing of insights between expert operators.

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