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Continuous Monitoring and Partial Water Softening for Cooling Tower Water Treatment

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Executive Summary

Background

Cooling towers are an integral component of many refrigeration systems, providing comfort or process cooling across a broad range of applications. They are the point in the system where heat is dissipated to the atmosphere through the evaporative cooling process. Cooling towers are commonly found in industrial applications and are also often used in water-cooled chilled water plants in medium to large commercial buildings. Continuous monitoring and partial water softening for cooling towers used in medium to large commercial buildings are the focus of this paper.

Cooling towers consume large amounts of water. Cooling tower-related water consumption is one of largest potable water loads within buildings in the United States, with substantial building water use associated with heating and cooling. Regional water shortages have highlighted a need to reduce water consumption; the U.S. General Services Administration (GSA) and Executive Order 13834 place priority on reducing water consumption[1]. This priority has fueled interest in the identification, investigation, and potential broad deployment of cost-effective opportunities to reduce water use, such as alternative water treatment (AWT) technologies for cooling towers.

Traditional water treatment approaches use chemicals to extend the ability of the water to hold scaling minerals in suspension, minimize corrosion, and prevent biological growth. This treatment protects the chillers and cooling tower equipment; however, even when chemicals are used regularly, a certain percentage of condenser water must be drained and made up with fresh water to maintain system water quality parameters. In addition, the use of chemicals sometimes creates a waste disposal issue and can cause building owners to incur additional fees, such as disposal or wastewater charges. To manage cooling tower water treatment, GSA typically contracts with a company specializing in conventional chemical maintenance for a fixed fee.

While there are many types and vendors of AWT systems, this project assesses the effectiveness of one technology provided by Aqualogix. This system is a chilled water plant monitoring and control system aimed at optimizing system performance by reducing the blowdown occurrences used to remove mineral build-up. The technology consists of two components – continuous programmable logic control (PLC) monitoring and side-stream filtration with partial water softening. PLC monitoring calculates cycles of concentration (CoC) and determines the optimum amount of blowdown water required to satisfy all water chemistry requirements. Side-stream filtration removes suspended matter and improves biocide efficacy while precisely dispensing softened water to achieve optimal makeup water hardness. Unlike other AWT systems evaluated by GSA to date, this system does not replace the legacy treatment system but is used in addition to chemical water treatment. The vendor claims their technology will reduce water consumption, water discharge, and maintenance costs.

The AWT system evaluated in this demonstration is a commercialized technology. Given its commercialized state, the system evaluated in this report is at a Technology Readiness Level 9[2] according to National Aeronautics and Space Administration (NASA) definitions.

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[1] https://www.fedcenter.gov/programs/eo13834/

[2] https://esto.nasa.gov/files/trl_definitions.pdf

TRL 6 Prototype System Verified (System/process prototype demonstration in an operational environment).
TRL 7 Integrated Pilot System Demonstrated (System/process prototype demonstration in an operational environment).
TRL 8 System Incorporated in Commercial Design (Actual system/process completed and qualified through test and demonstration).
TRL 9 System Proven and Ready for Full Commercial Deployment (Actual system proven through successful operations in operating environment and ready for full commercial deployment).
TRL 10 Program Management and Market Development/Support Activities

This project assesses the effectiveness of this technology at lowering GSA's operating costs and reducing cooling tower blowdown while maintaining proper water treatment. Considering that water-cooled chilled water plants consume approximately 23% of a building's total water demand, any savings due to this technology could be significant. The application of this AWT technology has the potential benefits of:

- Reducing water and water/wastewater costs by reducing the amount of blowdown required, thus allowing the system to operate at higher CoC.
- Providing decision-making information for GSA building and energy managers for application in a portfolio of Federal buildings.

The GSA Proving Ground (GPG) program selected the Lloyd D. George Courthouse, located in Las Vegas, Nevada, as the test bed for evaluating the Continuous Monitoring and Side Stream Filtration technology provided by Aqualogix. The building is approximately 450,000 square feet and is cooled using three chillers that receive cooling water from three rooftop cooling tower cells. There are two chillers rated at 450 tons and one chiller rated at 350 tons. The cooling season tails off in November and picks back up in April although some cooling is required year round. The cooling towers historically operated at about 2.8 CoC. Water treatment consists of an anti-corrosion agent, two separate biocides, and sulfuric acid to prevent scaling. The facility was selected for this evaluation based on site selection criteria developed by the National Renewable Energy Laboratory (NREL), including a relatively long cooling season with consistent loads, minimizing the overall required evaluation period, and water chemistry and tower operation broadly representative of conditions found across GSA's portfolio.

The AWT system consists of a PLC controller and side stream filtration system mounted on a skid that is approximately 91 inches tall, 40 inches long, and 40 inches wide. A separate brine tank is required, and has a 30 by 30 inch footprint (black tank in Figure 1). The skid weight is 1,275 pounds (lbs) dry weight (1,625 lbs operating weight) and is located in the chiller room as shown in Figure 1, below.

Figure 1. – AWT System at Lloyd D. George Courthouse

Measurements taken at the site included the flow of makeup water and blowdown flow to and from the cooling towers and the AWT skid. Measurements of water in and out of the system define the CoC and the rate of evaporation. These values were used to characterize the baseline water usage as it relates to evaporation or load. The same water balance measurements were used to calculate the water usage after the AWT was installed and correlate it back to a facility load. Additionally, the energy used by the AWT skid was measured. Measurement and verification (M&V) also evaluated the level of effort required for installation and commissioning and the impact on operations and maintenance (O&M).

The quantitative and qualitative performance objectives for this evaluation and associated M&V results are summarized in Table 1, below.

Table 1. Performance Objectives

Quantitative Objectives	Metrics & Data	Success Criteria	M&V Results
Water/Wastewater Savings	Metered water consumption Metered blowdown	> 8% makeup water savings > 32% blowdown/wastewater	**Met** – Water consumption reduced by 15%. Blowdown reduced by 52%.
Maintenance Savings	Maintenance records for current cost of chemicals and labor during demonstration period and estimated future maintenance for the Aqualogix Lite system.	No chemical cost increase for legacy system (excluding salt). No increase in maintenance costs for cleaning and maintaining the system.	**Met** – No increase in chemical or maintenance costs (excluding salt).
Water Quality	Water quality testing	No degradation in water quality including pH, hardness, alkalinity, silica high range, chloride anions, salt anions, sulfate anions, phosphate, copper, iron, and biological growth.	**Met -** No substantial changes in water quality attributable to the vendor.
Cost Effectiveness	Simple Payback Savings-to-Investment Ratio (SIR)	< 5-year payback > 1.0 SIR	**Simple Payback -** 7.5 years. although the site cooling load was 1.6 million annual ton-hours, only about half of the estimated 3 million annual ton-hours. Higher cooling loads could result in better payback results. **SIR Met** - 2.0
Qualitative Objectives	**Metrics & Data**	**Success Criteria**	**M&V Results**
Ease of Installation	Interview with installer. Time required to install and configure	< 5 days to install and commission one cooling tower	**Met -** Technology was installed in 2 days.
Corrosion Monitoring	Continuous Electronic Corrosion monitoring for copper and mild steel using electrical resistance between probe points.	System is alarmed when the cooling tower water reaches a corrosive threshold using pH and conductivity monitors. Verified independently with plant meters for pH and conductivity.	**Met -** There were no corrosion excursions on the Aqualogix Lite system and therefore no alarms were seen.
Operability	Interview with operations and maintenance staff	Facility operators have no issues with technology	**Met -** No issues were reported by the site staff.

Quantitative Objectives	Metrics & Data	Success Criteria	M&V Results
Site Safety	Chemicals	No hazardous chemicals used by the Aqualogix Lite system.	**Met -** No additional chemicals used except for salt. Loading sacks of salt into a hopper did not constitute a health issue.

Testing consisted of a 1 month baseline period (September, 2018) and a three month evaluation period (July through September, 2019) enabling sufficient data to be acquired to account for differences in ambient temperature and cooling system duty between the baseline and evaluation periods.

Water and wastewater savings exceeded success criteria established at the project outset. The water consumption during the baseline period was 178 gallons per MMBtu of heat rejected. During the AWT testing period, water use dropped to 150 gallons per MMBtu for a savings of 15% or 27 gallons per MMBtu. Wastewater discharge reduction was calculated to be 52%. The annual load was measured at 19,356 MMBtu per year yielding a projected annual water savings of 528,673 gallons. Using this specific site's water rate of $12.59 per thousand gallons (kgals) and the estimated heat load for an entire year, the total annual water cost savings were estimated to be $6,656. Wastewater cost savings were not relevant in this case as the wastewater costs are a fixed monthly cost and independent of flow rates at this flow range. However, if wastewater rates were applicable, the economics could only be improved.

There were no chemical savings or additional costs as the legacy chemical treatment regime remained constant during both testing periods.

The cost of the AWT system equipment was $30,016 including shipping. The payback period calculation is outlined below in Table 2.

Table 2. Economic Summary

Description	Testbed[3]	Estimated GSA Portfolio[4]	Notes
COSTS			
Equipment cost for 200-1000 ton load ($)	$30,016	$30,016	Base unit only. No remote monitoring of pH, corrosion, ORP. Includes startup. Assumes $2,000 shipping and $1,473 for training. Pricing is discounted for GSA installations.
Installation cost ($)	$8,355	$8,355	$5,700 at testbed. $2,655 added to account for skid piping costs (piping was already in place on site at test bed from previously installed (and removed) AWT technology)
Annual maintenance increase ($/year)	$783	$783	$250 for annual calibration and salt receiving and loading; $533 for salt

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[3] Calculations using data measured at testbed during baseline testing.

[4] Calculations performed at target load and average GSA water costs of $16.76 per kgal.

Description	Testbed[3]	Estimated GSA Portfolio[4]	Notes
Annual water savings (kgal/year)	528,673	983,273	Target load for technology is 3 million annual ton-hours/250 ton average load. Although test bed was projected to meet target load[5], the measured load was 1.6 million annual ton-hours or 187-ton average load. Portfolio estimate reflects target load.
Annual water cost savings ($/year)	$6,656	$16,480	Testbed water cost $12.59/ kgal; portfolio estimate reflects GSA average water rate of $16.76/kgal
Annual technology electricity use (kWh/year)	7,735	7,735	
Annual increase in electricity cost ($/year)	$774	$851	Testbed electricity cost $0.10/ kWh; portfolio estimate reflects GSA average electric rate of $0.11/ kWh
Total annual savings ($)	$5,100	$14,846	
Payback (years)	7.5	2.6	
SIR	2.0	5.8	

Column 2 (Testbed) in Table 2, above, represents the initial results. Column 3 (Estimated GSA Portfolio) shows the estimated economics had the system operated at 3 million ton-hours of cooling for a year and assuming a water cost of $16.76 per thousand gallons which represents the GSA portfolio average. The size range of 3 million ton-hours per year was the initial system size goal for the testing program. Economics are sensitive to scale and the chosen site had less load than originally anticipated.

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[5] Data to correctly identify annual load is essential to right sizing the system and optimizing payback. The site provided inaccurate data, therefore the system was oversized, and payback was extended.

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I. Introduction

A. WHAT WE STUDIED

A cooling tower is a heat rejection device that rejects heat to the atmosphere from a water-cooled chilled water plant. The heat is rejected to the atmosphere through the evaporative cooling process, and cooling towers are commonly used in water-cooled chilled water plants in medium and large commercial buildings. The continuous evaporation of condenser water leaves behind any mineral content it carried upon entry into the condenser water system. The make-up water has a natural amount of mineral impurities (e.g., silica, calcium, and magnesium), so the remaining condenser water will have an ever-increasing amount of impurities as progressively more water evaporates. These impurities eventually precipitate out (since water can hold only so much of these impurities in suspension), resulting in solid precipitate. This solid precipitate is commonly called scale and will collect on various surfaces. Scale has a detrimental effect on heat transfer surfaces; it lowers the efficiency of the heat transfer process, causing the chiller to use increasingly more energy over time to produce the same amount of cooling. Typical water treatment consists of injecting chemicals into the condenser water for the following three purposes:

- Chemicals called “scale inhibitors” alter the natural ability of water so that it can hold a higher concentration of minerals.
- Chemicals called “corrosion inhibitors” decrease corrosion in piping systems; and
- Chemicals called “biocides” and “algaecides” mitigate biological growth in the cooling tower where warm water is exposed to air.

In addition to the use of chemicals to treat the cooling tower water, a portion of the cooling tower water is typically dumped down the drain. This is commonly known as tower blowdown. When blowdown takes place, fresh makeup water is introduced, which increases cooling tower water usage. Therefore, blowdown has the effect of lowering the chemical/mineral content of the remaining condenser water and increasing the cycles of concentration (CoC) of the cooling tower.

This alternative water treatment AWT system is self-contained on a skid, where it has a side-stream filtration to reduce COC; the system is controlled by a PLC (Figure 2). The AWT system aims to reduce blowdown requirements in order to save makeup water and wastewater discharge. The technology only uses a side-stream of the condenser water and for this demonstration the system was able to utilize pre-existing taps and piping that were installed from a prior technology test. System blowdown was controlled by a newly installed AWT skid with the existing blowdown controller acting as a backup failsafe. Blowdown, along with regeneration waste water, discharged into a drain located in the adjacent room (Figure 3).

Figure 2. Aqualogix Lite Skid Location (Credit: Gregg Tomberlin, NREL)

Figure 3 – Aqualogix Lite Blowdown Location (Credit: Gregg Tomberlin, NREL)

The skid is tied into the condenser water supply and return lines and also receives city water makeup as shown below in Figure 4.

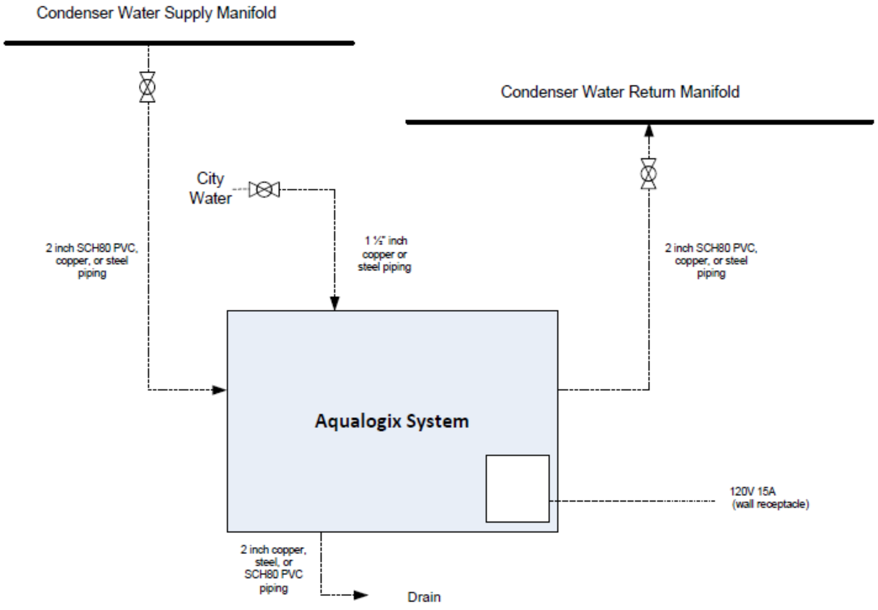


Figure 4 – System integration (Credit: Aqualogix-Mike Richardson)

This chilled water plant monitoring and control system optimizes chilled water system performance by reducing the amount of blowdown water used to remove mineral build-up and reducing solids that build up in the system. The partial softening technology consists of two components—continuous PLC monitoring and side-stream filtration. PLC monitoring calculates CoC and determines the optimum amount of blowdown water required to satisfy all water chemistry limits. In theory, this optimization limits unnecessary blowdown saving water and the associated costs for makeup and discharge. Side-stream filtration removes suspended matter and may improve biocide efficacy while precisely dispensing softened water to achieve optimal makeup water hardness. This could reduce biocide chemical usage, although the biocide rate was not reduced for this evaluation. The technology utilizes monitoring and partial water softening, thereby achieving optimal makeup water hardness levels.

The use of partially purified makeup water for an open recirculating cooling system is common practice. This technology improves on current methods by adding continuous programmable logic control (PLC) monitoring and control. This method could improve on existing technologies by feeding purified (or partially purified) makeup water into an open recirculating cooling system in proportion to the blowdown flow. The AWT system controls the injection of the purified makeup by using a signal from a water meter that is installed on the blowdown line. The signal from the blowdown actuates an automatic valve on the inlet or outlet piping of the purification device. Additionally, the cooling water conductivity is monitored and the system will prevent the inlet (or outlet) valve from opening, should the conductivity fall below a preset limit. The percentage purification is determined by the following equation:

> Purification Percent = ((cycles x concentration of constraining factor in makeup) – upper limit of constraining factor in condenser water) / (cycles x concentration of constraining factor in makeup).

By locking out the valve in the event of low conductivity, overfeed of purified water is limited. This serves as a safeguard to prevent the overfeeding of purified water. The CoC at the building prior to the installation of the system was approximately 2.8.

The manufacturer also claims that side-stream filtration improves the efficacy of the systems biocide. The biocide is not consumed by the suspended particles as much due to the filtration that removes particles to 5 microns.

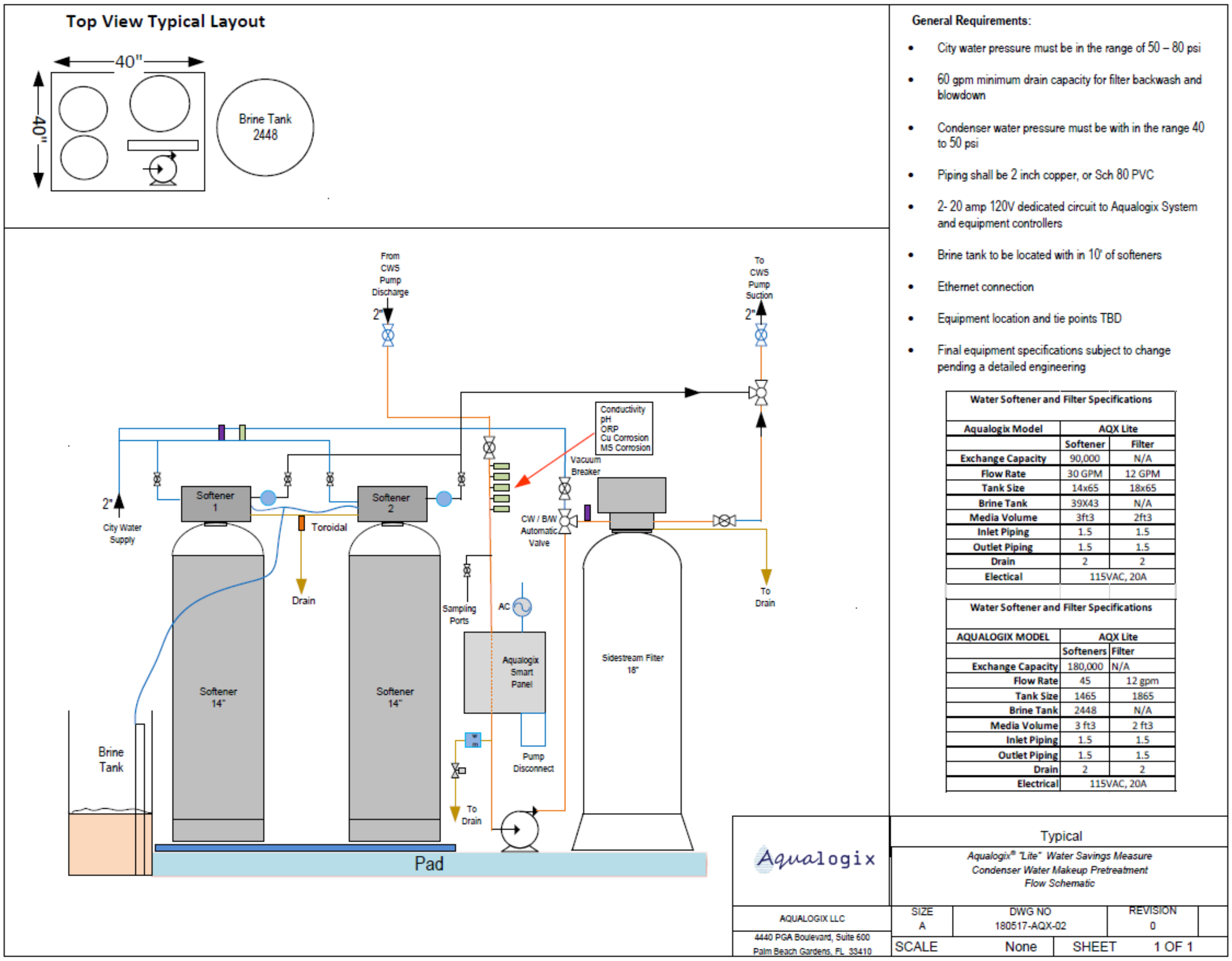
The AWT system is self-contained and does not require remote monitoring. The vendor does ask that firewall ports be configured to allow remote access if remote monitoring and email alerts are desired, but this is not a required feature for the system to operate.

According the manufacturer, the AWT technology is deployed at numerous facilities including but not limited to:

- Department of the Interior HQ, Washington D.C.
- Corpus Christie Army Depot, Corpus Christi, Texas
- Georgia Tech, Atlanta, Georgia
- Max Planck Florida Institute for Neuroscience, Jupiter, Florida

The costs for various system sizes was provided by the manufacturer in order to assess cost effectiveness at other U.S. General Services Administration (GSA) sites.

A schematic of the vendor's system is shown below in Figure 5.



General Requirements:

- City water pressure must be in the range of 50 – 80 psi
- 60 gpm minimum drain capacity for filter backwash and blowdown
- Condenser water pressure must be with in the range 40 to 50 psi
- Piping shall be 2 inch copper, or Sch 80 PVC
- 2- 20 amp 120V dedicated circuit to Aqualogix System and equipment controllers
- Brine tank to be located with in 10' of softeners
- Ethernet connection
- Equipment location and tie points TBD
- Final equipment specifications subject to change pending a detailed engineering

Water Softener and Filter Specifications

Aqualogix Model	AQX Lite	
	Softener	Filter
Exchange Capacity	90,000	N/A
Flow Rate	30 GPM	12 GPM
Tank Size	14x65	18x65
Brine Tank	39X43	N/A
Media Volume	3ft3	2ft3
Inlet Piping	1.5	1.5
Outlet Piping	1.5	1.5
Drain	2	2
Electical	115VAC, 20A	

Water Softener and Filter Specifications

AQUALOGIX MODEL	AQX Lite	
	Softeners	Filter
Exchange Capacity	180,000	N/A
Flow Rate	45	12 gpm
Tank Size	1465	1865
Brine Tank	2448	N/A
Media Volume	3 ft3	2 ft3
Inlet Piping	1.5	1.5
Outlet Piping	1.5	1.5
Drain	2	2
Electrical	115VAC, 20A	

Typical

Aqualogix® "Lite" Water Savings Measure
Condenser Water Makeup Pretreatment
Flow Schematic

AQUALOGIX LLC
4440 PGA Boulevard, Suite 600
Palm Beach Gardens, FL 33410

SIZE	DWG NO	REVISION
A	180517-AQX-02	0
SCALE None	SHEET 1 OF 1	

Figure 5. Diagram AWT Skid (Credit: Aqualogix-Mike Richardson)

The two components that need to be measured to account for water savings are (1) water consumption and (2) heat rejection from the cooling loop. Water consumption, or makeup water, was measured via onsite water meters and recorded to a data file. Blowdown water flows were also directly metered and recorded for both the baseline and the testing period in this study.

The heat rejected from the condenser loop of the chilled water plant was measured by using the following formula:

Heat rejected (Btu's/hour) = water evaporated (lbs/hr) x evaporation enthalpy (Btu's/lb)

where:

Water evaporated = Makeup – blowdown – drift losses

The water usage during the baseline testing was measured and the total amount of heat rejected through evaporation during the same period was calculated, yielding a water usage number per heat rejected in gallons per MMBtu. The same approach was used during the AWT testing period and the gallons per MMBtu for both cases were compared to understand changes in water usage with relation to cooling load.

The water quality was analyzed through assessment of the water quality reports delivered monthly by the site's water treatment contractor. Water quality metrics measured included: conductivity, pH value, hardness, PTSA, alkalinity, bacteria, and corrosion rates for mild steel and copper.

The AWT system evaluated in this demonstration is a commercialized technology. Given its commercialized state, the system evaluated in this report is at a Technology Readiness Level 9[6] according to National Aeronautics and Space Administration (NASA) definitions.

B. WHY WE STUDIED IT

Cooling tower-related water consumption is one of largest potable water loads within buildings in the United States. A breakdown of water consumption in office buildings is provided in Figure 6 and shows that about 28% of water use is associated with heating and cooling due to the evaporative cooling demands associated with all water-cooled air conditioning systems and evaporative based air conditioners.

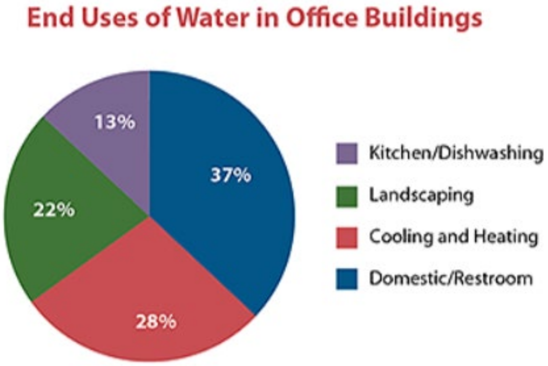


Figure 6. Office water end uses[7]

Cooling towers can be found in all states throughout the country, and this AWT technology could save water in most if not all climate zones. Although the technology can save water in practically all climate zones, facilities located in hotter climates with a cooling season that lasts for more than 5 or 6 months per year will have higher cooling tower utilization and consequently have greater potential for cooling tower water savings.

Although the number of cooling towers in each GSA region is unknown, it is expected that each region has numerous cooling towers that could capitalize on this technology to assist in reducing water consumption for each GSA region.

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[6] https://esto.nasa.gov/files/trl_definitions.pdf

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TRL 10 Program Management and Market Development/Support Activities

[7] https://www.epa.gov/watersense/types-facilities

II. Evaluation Plan

A. EVALUATION DESIGN

Study Design and Objectives

The technology evaluated in this report was assessed according to three main criteria set out by GSA in the original request for proposals (RFP):

1. Verify water cost reductions for the demonstration building.
2. Verify operations and maintenance (O&M) costs and plant personnel acceptance.
3. Provide decision-making information so that GSA building and energy managers can effectively assess technology applicability for GSA's portfolio of federal buildings.

Comparison of performance during a baseline period versus a testing period (using the AWT system) was the basis of the technology demonstration approach. The principal variable that changed between the baseline period and the AWT test case was the quantity of cooling required and, therefore, the amount of heat rejected (and water evaporated) by the cooling tower. The normalization of water savings to cooling demand allowed for effective comparison of the AWT technology to standard water treatment technologies. It also enables the estimation of savings for other buildings. With an appropriate understanding of cooling demand and water quality at other GSA sites it is possible to predict potential water savings that may be achievable with the AWT system assessed herein.

This report addresses water and cost savings associated with the AWT system, and the water quality data provided by the AWT system. To quantify the performance of the AWT system, metering equipment was installed to measure data for inputs, outputs, and delivered results. This data was used to model the overall performance of the AWT system with respect to water use, energy use, and water quality. This performance based modeling approach enabled the comparison of the AWT system to the baseline water treatment system using the same framework. Using the data gathered from the baseline and the testing periods, the performance objectives were analyzed for compliance. Quantitative and qualitative performance objectives for the project are provided in Table 3 and Table 4, respectively.

Table 3. Quantitative Objectives

QUANTITATIVE OBJECTIVES	METRICS AND DATA	SUCCESS CRITERIA
Water/ Wastewater Savings	Metered water consumption Metered blowdown	> 8% makeup water savings > 32% blowdown / wastewater
Maintenance Savings	Maintenance records for current cost of chemicals and labor. Maintenance records during demonstration period and estimated future maintenance for the Aqualogix Lite system	No chemical cost increase for legacy system (excluding salt). No increase in maintenance costs for cleaning and maintaining the system.
Water Quality	Monthly water quality testing	No degradation in water quality including pH, hardness, alkalinity, silica high range, chloride anions, salt anions, sulfate anions, phosphate, copper, iron, and biological growth.
Cost-Effectiveness	Simple payback SIR	< 5-year payback > 1.0 SIR

Table 4. Qualitative Objectives

QUALITATIVE OBJECTIVES	METRICS AND DATA	SUCCESS CRITERIA
Ease of Installation	Interview with installer Time required to install and configure	< 5 days to install and commission one cooling tower
Corrosion Monitoring	Continuous Electronic Corrosion metering for copper and mild steel using electrical resistance between probe points.	System is alarmed when the cooling water reaches a corrosive threshold using PH and conductivity monitors. Verified independently with plant meters for PH and conductivity.
Operability	Interview with operations and maintenance staff.	Facility operators have no issues with technology
Site Safety	Chemicals	No hazardous chemicals used by the Aqualogix Lite system.

Water Quality

GSA has developed the water chemistry standards shown in Table 5, as a guideline to determine the acceptability of cooling tower basin water quality for a given water treatment technology. Operations staff and water treatment technology vendors performed monthly monitoring of these parameters to characterize the system performance. Adherence to these ranges is not the only indicator of a technology's success. The operation of a water treatment technology is unique and the materials used in its design may result in water quality that falls outside the ranges defined in the project specifications. In the application of these criteria, a site should consider site-specific water quality constraints, whether due to influent potable water or discharge permit limitations, and make selections accordingly.

Table 5. Water Quality Criteria (as defined by GSA)

Test	Acceptable Ranges
T alkalinity (ppm)	100 – 1000
pH	7.3 – 9.0
Chloride (ppm)	10 – 500
CoC	>2
Total Hardness (ppm)	500 – 1500
Phosphate (ppm)	8 – 15
Conductivity (mmHos)	<2,400
Bacteria Count (cfu)	<80,000
Water Appearance	Clear
Iron (ppm)	<4
Calcium Hardness (ppm)	<500
Magnesium Hardness (ppm)	<100
Chlorides (ppm)	<250
Salt (ppm)	<410
Sulfates (ppm)	<250
Silica (ppm)	<150
ORP (mV)	>300
90-day Copper Coupon (mpy)	<0.2
90-day Mild Steel Coupon (mpy)	<3
90-day Galvanized Steel (mpy)	<4
90-day Stainless Steel (mpy)	<0.1

B. INSTRUMENTATION PLAN

Two key measurements used to assess water usage of a cooling tower are the blowdown water flow and the makeup water flow. Instrumentation was installed to measure both flow rates for the existing cooling towers and for the AWT system. Figure 7 below shows the piping and meter arrangement for the cooling tower blowdown and Figure 8 shows the new makeup water meter installation location outside at the cooling towers. A new blowdown meter was installed at the same location as the existing blowdown meter. This meter was used to measure blowdown during the baseline testing. During the AWT test period, blowdown takes place at the AWT skid. The blowdown was measured at the skid and also at the original location to ensure no water was lost through this line, even though blowdown should be nonexistent at that point.

Figure 7. Cooling Tower Blowdown Meter and Piping (Credit: Gregg Tomberlin, NREL)

Figure 8. Cooling tower makeup flow meter location (Credit: Gregg Tomberlin, NREL)

Monitoring points with, and without, the AWT system are shown in Figure 9 and Figure 10, respectively.

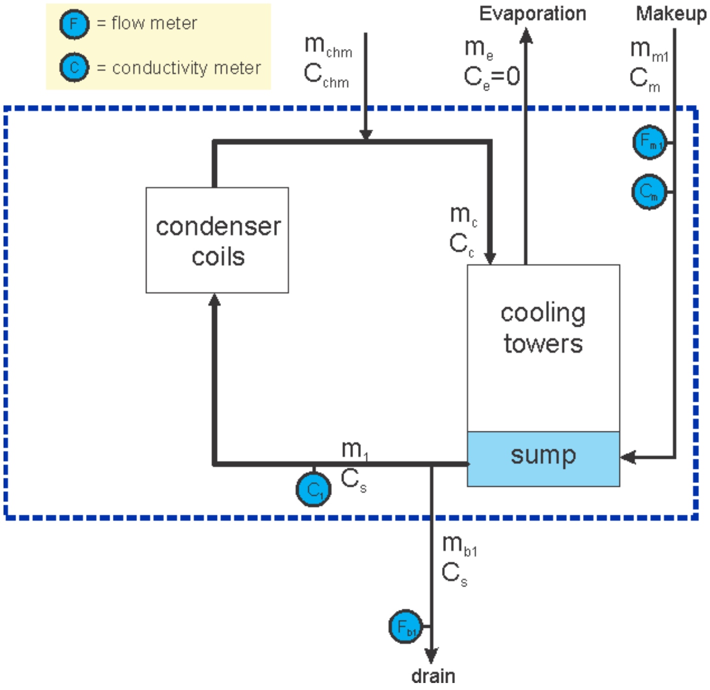

Figure 9 – Baseline period monitoring points w/o AWT (Credit: Greg Barker. Mountain Energy Partnership)

Figure 9 above indicates that makeup water into the system and blowdown water from the system (drain) were measured during the baseline testing. The evaporation shown at the top of the diagram is calculated as the difference except for small amounts of drift loss. Conductivity readings for the makeup and recirculating flows were also recorded.

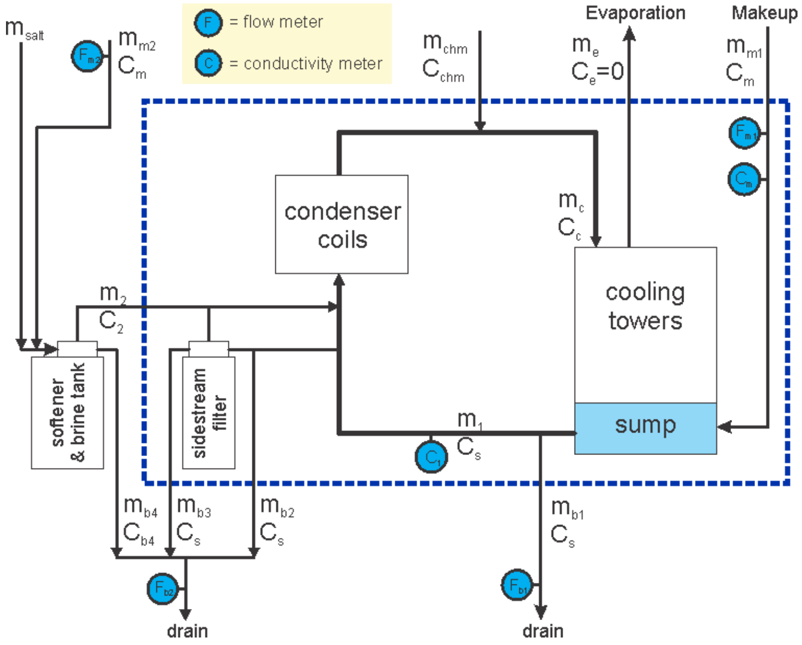

Figure 10 – Evaluation period monitoring points w/AWT

(Credit: Greg Barker. Mountain Energy Partnership)

Figure 10 shows the additional instrumentation and data that were recorded during the AWT test period. These measurements include the blowdown and makeup flows for the AWT skid.

To determine the metrics described previously, the data points described in Table 6 were collected using the indicated instruments. This set of monitoring points is preliminary and may change as more is learned about the demonstration site. Data was logged every minute during the testing periods.

The goal of the instrumentation plan for this technology demonstration focused on metering water and energy use of the building cooling towers and chillers. To develop this measurement, instrumentation was added for the data points described in Table 6.

Table 6. Monitoring Points and Instrumentation

Monitoring Point	Sensor/Monitor	Notes
Condenser water total flow rate	Existing Building Automation System	
Blowdown flow rate	New totalizing flow meter replacing the existing meter	1-1/2 inline copper line. Replace existing non-functional flow meter
AWT blowdown and regen flow rate	Totalizing flow meter at the AWT skid discharge	
Water input to AWT skid	Totalizing flow meter at the AWT skid	In new line that was run from the existing treated water system
Blowdown conductivity	Existing site meter for cooling tower blowdown. Monitor at AWT skid	Mounted in line. Tie into 4-20 mA output
Blowdown pH	Existing site meter – Walchem WebMaster One. New output board installed.	Mounted in line. Tie into 4-20 mA output
Blowdown ORP	Existing Site Meter – Walchem WebMaster One . New output board installed.	Mounted in line. Tie into 4-20 mA output
AWT skid energy usage	Plug flow meter at skid	
Makeup water flow rate	New totalizing flow meter in addition to the existing FTB4100 series totalizing flow meter	2-1/2 inline copper line. Install at cooling towers prior to splitting to each cell.
Ambient dry bulb temperature	Monitor located outside	
Ambient relative humidity	Monitor located outside	
Cooling tower basin corrosivity	AWT internal corrosion monitoring device checked with new pH and conductivity meters	Located on AWT skid. Data to be downloaded and transferred to NREL
Cooling tower overflow	Level switches that will sense an overflow of the cooling tower basin and alert staff	Need to monitor cooling tower water losses due to overflow
Data logging equipment	2-3 Campbell Scientific CR1000 data loggers with cell phone modem, required peripheries, and other supplies	

Data was collected remotely at NREL's office in Golden, Colorado. Information was sent via a modem connection from a data logger. Installation of instrumentation took place prior to baseline testing, and was non-invasive. Commissioning took place immediately after installation and data was collected until the end of the AWT test period.

C. TEST BED SITE

Candidates for this technology are buildings or other installations that have a cooling tower used for evaporative cooling on site. The minimum facility size and cooling tower capacity size applicable for this particular technology was determined during the course of this demonstration.

The Lloyd D. George Federal Building is located at 333 Las Vegas Blvd S in Las Vegas, Nevada as shown in Figure 11 and pictured in Figure 12. The building is approximately 450,000 square feet and has a relatively long cooling season (approximately 8 to 9 months of the year). The site currently utilizes three chillers. Two chillers are rated at 350 tons and one at 450 tons. The condensers for the chillers utilize water from three cooling tower cells located on the roof of the building. The cooling system typically runs at about 2.8 CoC.

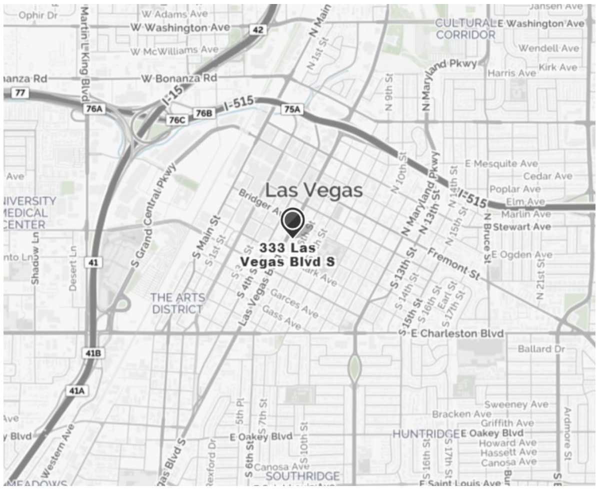

Figure 11. Location of the Lloyd D. George Federal Building (MapQuest)

Figure 12. Picture of the Lloyd D. George Federal Building (Credit: Gregg Tomberlin, NREL)

The annual daily range of high and low temperatures for Las Vegas, Nevada are shown in Figure 13.

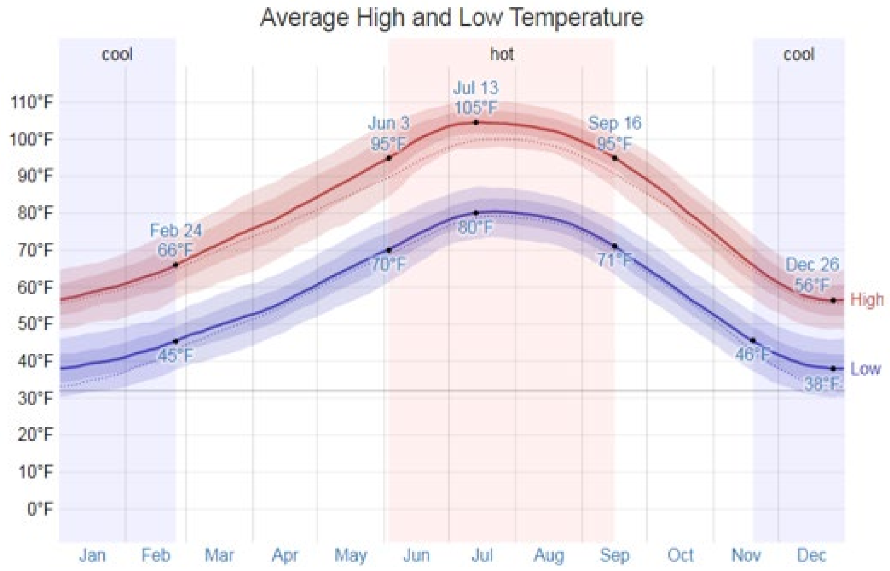

Figure 13. Average daily temperature range for Las Vegas, Nevada.[8]

D. METHODOLOGY

The effectiveness of the technology was demonstrated by comparison between the measured metrics with and without the AWT technology installed. The initial testing period – the baseline test period – was conducted before the AWT technology was installed.

After all instrumentation was installed and tested, the baseline test period data collection began. The demonstration test period with the AWT technology installed and operational began after adequate baseline data had been collected. The actual testing schedule is shown in Figure 14.

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[8] https://weatherspark.com/y/2228/Average-Weather-in-Las-Vegas-Nevada-United-States-Year-Round

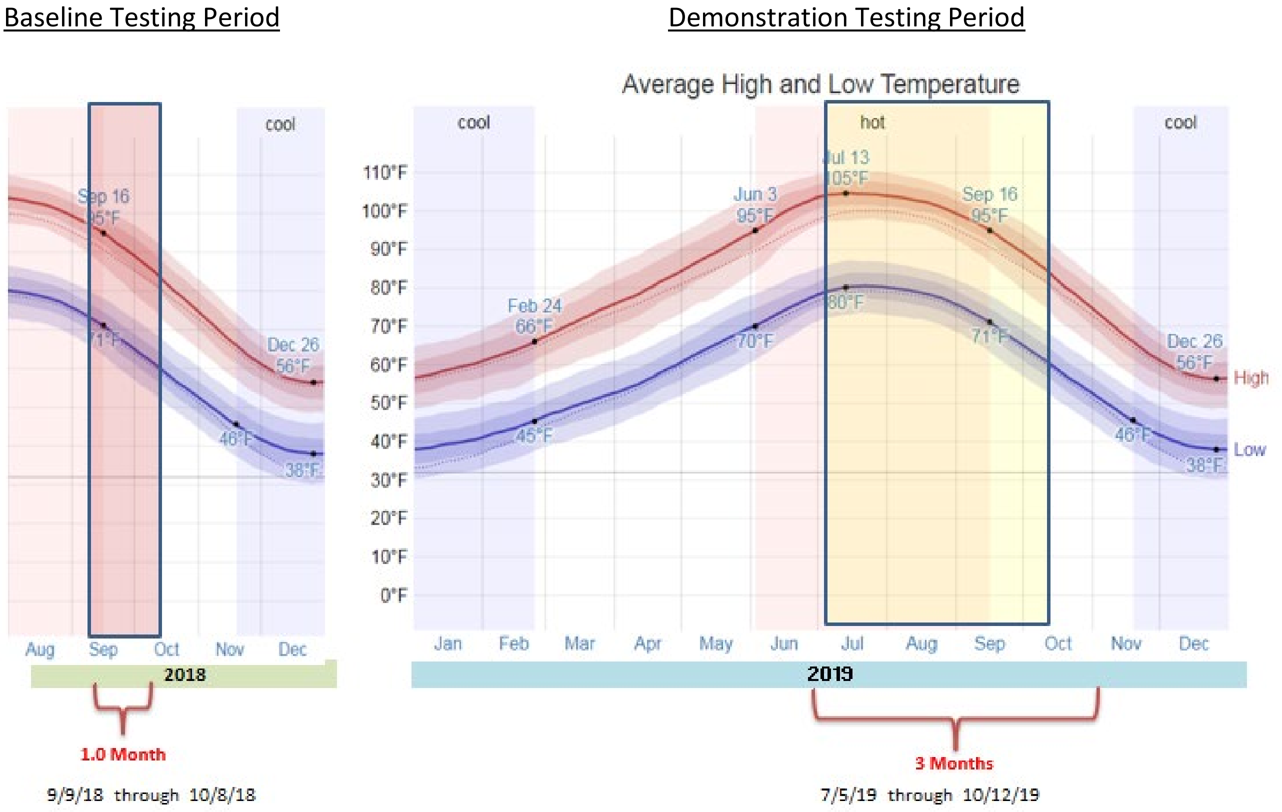

Figure 14. Baseline and testing schedules[9]

The data obtained was used to evaluate whether the AWT technology represents an improvement in the system. The measurement of energy and water usage and associated costs enabled a comparison of the changes in system performance. The costs for O&M were factored into the economic performance to provide a payback and a SIR for the AWT system based on its implementation and operating costs and savings.

III. Demonstration Results

This measurement and verification (M&V) demonstration study compares the operation of the existing cooling water system to the AWT technology installed at the test site. The time period without the technology installed is termed the baseline and is meant to represent as-is operation of the building systems. More information on the baseline is given in the Methodology section. Results regarding water and energy usage were collected and normalized to the system load for comparison. Calculations were done to estimate the total annual water usage for the baseline and the AWT technology. Water savings is the primary driver for the economics, although other costs for maintenance and energy usage were included. The annual savings were compared to the total installation cost to arrive at values for simple payback and (SIR).

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[9] https://weatherspark.com/y/2228/Average-Weather-in-Las-Vegas-Nevada-United-States-Year-Round

It is important to note that the technology was to be applied at a site where the cooling load was rated at 3 million ton-hours or greater. The measured annual load for the site for the year during testing was approximately 1.6 million ton-hours, which is less than the initial testing criteria. Had the load been better identified, the AWT vendor could have supplied a smaller system at less cost to satisfy the site requirements. Also, savings are highly sensitive to economy of scale, further depressing the economic payback and SIR values calculated.

A. QUANTITATIVE RESULTS

Quantitative results are discussed below relative to the objectives set out at the start of the evaluation and are summarized in Table 7 below.

Table 7. Quantitative Objectives and Results

Quantitative Objectives	Metrics & Data	Success Criteria	M&V Results
Water/Wastewater Savings	Metered water consumption Metered blowdown Ambient temperature and humidity.	> 8% makeup water savings > 32% blowdown/ wastewater	**Met** – Water consumption reduced by 15%. Blowdown reduced by 52%
Maintenance Savings	Maintenance records for current cost of chemicals and labor. Maintenance records during demonstration period and estimated future maintenance for the Aqualogix Lite system.	No chemical cost increase for legacy system (excluding salt). No increase in maintenance costs for cleaning and maintaining the new system and ancillary equipment.	**Met –** No increase in chemical or maintenance costs (excluding salt)
Water Quality	Water quality testing	No degradation in water quality including pH, hardness, alkalinity, silica, chlorides, and biological growth.	**Met -** No substantial changes in water quality were recorded.
Cost Effectiveness	Simple Payback SIR	< 5-year payback > 1.0 SIR	**Simple Payback partially met** - 7.5 years. The site cooling load was 1.6 million annual ton-hours, only about half of the estimated 3 million annual ton-hours. Higher cooling loads could result in better payback results. **SIR Met** - 2.0

Water Savings

To accurately assess the water savings from the AWT system, it was necessary to calculate pre-installation cooling tower water usage. Makeup water and blowdown was metered prior to the installation of the AWT system to develop a baseline. The AWT increased the CoC by modifying the conductivity setpoint on the cooling tower controller. The result was a 52% reduction in blowdown after the installation of the AWT system. The baseline CoC averaged 2.8. Once the AWT system was engaged, the CoC averaged 4.2 resulting in makeup and blowdown water savings. The degree to which the CoC is raised is proportional to the water savings. In other GSA locations, the potential for water savings could be higher depending on the makeup water quality. During the AWT testing period, blowdown flow was taken from the AWT skid and not the cooling tower. This flow was measured as well as the cooling tower blowdown to ensure that all blowdown was coming from the AWT skid. Water rejection resulting from backwashing the side-stream filter was also accounted for.

Typical water related costs are for the water makeup to the cooling tower as a result of evaporation losses, drift losses and blowdown. Secondly, there is often a cost to discharge the blowdown water. This cost is generally combined as a single fee, but it is important to measure both flow rates. Flow meters were installed on both lines to measure the amount of water in and out of the system.

The water flows are expressed as “flow per ton of heat rejected” (kgals/ton) by the cooling tower. The flows are measured with meters and the tons of heat rejected is calculated as:

Evaporated Water (gallons) x 8.345 (lbs/gallon) x heat of vaporization (Btu/lb)

and:

Evaporated Gallons = Makeup (gallons) – blowdown (gallons) – drift (gallons)

This allowed for all water consumption to be normalized and enable effective comparison between the baseline and demonstration periods.

Additionally, a factor was applied to account for water losses in the system due to drift and minor leakages. During the baseline data period, the CoC was measured using both water balance and conductivity methods as described below.

$$\text{Water Balance} \quad - \quad \text{CoC} = \frac{\text{Makeup}}{\text{Blowdown + losses}}$$

$$\text{Conductivity} \quad - \quad \text{CoC} = \frac{\text{Blowdown Cond.}}{\text{Makeup Cond.}}$$

System losses are not directly measured but were estimated using these two equations. The makeup and blowdown flows are measured quantities utilizing flow meters. The system losses are estimated by inputting a value in the denominator of the first equation that yields a CoC identical to the one calculated in the second equation. For various data points at different loads, this value was different. The losses are closely estimated at various loads using the following equation:

$$\%\ \text{losses} = 0.0014 \ \times \ \text{evaporation rate (liters/minute)} + 0.0118$$

This equation was applied during the evaluation period to account for water losses due to drift or other small losses. The resulting losses were deducted from the water balance allowing calculation of the cycles of concentration using the water balance equation above in lieu of the conductivity equation.

Water savings exceeded the target goal by reducing the amount of blowdown and subsequent makeup water required. The baseline water consumption of the system was measured from September 9, 2018 through October 8, 2018 for a total of 30 days. The AWT water treatment system was monitored from July 5, 2019 through October 12, 2019 for a total of 99 days (Table 8).

Table 8. Water Savings

	Baseline	AWT Testing	Units
Testing Period	30	99	days
Blowdown	128,114	281,056	gallons
Makeup	394,456	1,517,488	gallons
Drift losses	12,030	80,670	gallons
Evaporation	254,312	1,155,762	gallons
Evaporative heat	2,217	10,074	MMBtu
Water consumption per heat rejected	177.9	150.6	Gallons per MMBtu
CoC	2.8	4.2	

As shown in Table 8, water consumption during the testing period was 178 gallons per MMBtu of heat rejected. During the AWT testing period, water use dropped to 150.6 gallons per MMBtu for a savings of 15.3%. Wastewater discharge reduction was calculated to be 52%. Both were well above the targeted values. Using the sites water rates of $12.59 per thousand gallons (kgals) and the estimated heat load for an entire year, the total annual water cost savings were estimated to be $6,657. Wastewater cost savings are not applicable as the wastewater costs are a fixed monthly cost and independent of flow rates at this flow range.

Maintenance Savings

To verify the O&M costs or savings, the following data was collected:

- Estimated changes in labor costs for cleaning cooling towers and condenser tubes
- Cost of O&M labor and chemicals for the existing baseline system
- Estimated O&M labor and materials cost for maintaining the AWT system as provided by the vendor

The operation of the water treatment system was monitored over the demonstration period to ensure that the operation of the unit did not cause any problematic issues. O&M staff were interviewed to understand any issues related to the system.

The operational labor consisted of loading salt occasionally from 40 pound bags. The site deemed this effort to be negligible and indicated that it does not add labor costs as the effort is minor and infrequent. The cost of the salt was included in the economics. It was assumed that the annual salt usage would be 3,228 pounds at a cost of $0.165 per pound for a total annual salt cost of $533.

O&M for the unit consists primarily of semi-annual system checks and annual instrument calibration. These items can be contracted through the vendor with the majority of the costs being travel to the site. The site maintenance personnel have opted to do this work themselves to avoid the cost of an annual maintenance contract. The AWT supplier will provide training to do this work for a one-time fee of $1,473 (including materials and special tools) that was included in the capital cost. An increase in site labor costs was included at $250 per year to cover the labor for the system checks and annual calibration, representing a total increase for O&M costs of $783/yr.

Energy Savings

Energy savings can be realized based on the technology's ability to remove scale from a system that has existing fouling and to reduce fouling between cleanings. Scale build-up on heat exchanger tubes can reduce heat transfer substantially with only a thin layer of scale. This loss in heat transfer results in higher energy use to achieve the desired performance. While energy savings are likely if scale is reduced, energy savings were not part of the AWT technology claim and were not evaluated.

There was no scale present on the tubes prior to testing. The condenser tubes were examined after the testing and no scale had accumulated as seen in Figure 15.

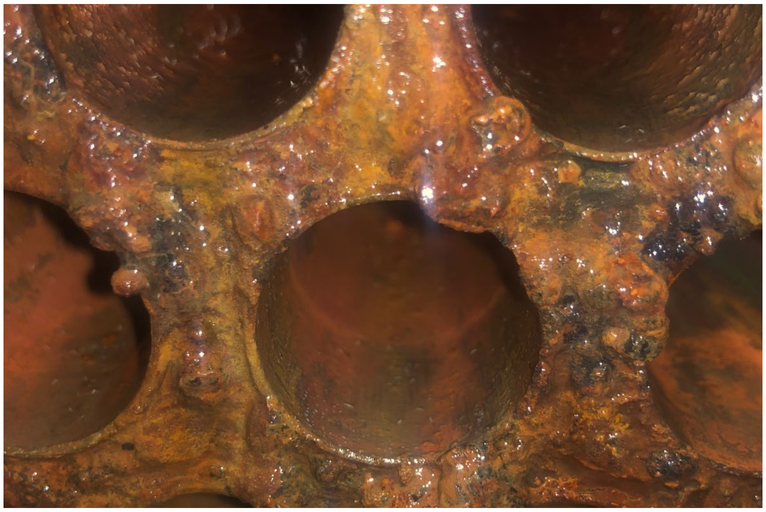


Figure 15. Condenser tubes after AWT testing (Credit: Jacob Lewis, GSA)

Energy usage for the system was calculated by measuring the average power usage during the testing period. The skid usage averaged 0.833 kW. Assuming 8,760 hours annually and a cost of electricity of $0.10 per kWh, the annual energy usage was calculated to be $774.

Chemical Savings

Another important M&V objective is to verify the usage of cooling tower chemicals during both phases of testing. The AWT vendor is not claiming any reduction in chemical usage as part of the testing program but it is important to verify that there is no increase in chemical usage and to note any reduction. Any changes in chemical usage were evaluated using input from the cooling tower contractor in charge of chemical supply and usage. Changes in chemical usage were documented during the AWT test period and there was no noticeable increase in chemical usage.

Water Quality

On a monthly basis, cooling towers are tested for effectiveness of water treatment, including pH, conductivity, biological dosage level, scale, and corrosion inhibitors. Chemicals and biological treatment dosage and water blowdown rate are adjusted, as required. GSA typically runs a cooling tower that uses standard chemical-based water treatment between 3 to 6 CoC. GSA has developed the water chemistry standards, shown in Table 9, as a guideline to determine the acceptability of cooling tower basin water quality for a given water treatment technology. It should be noted that adherence to these ranges is not the only indicator of a technology's success. The operation of a water treatment technology is unique and as the function of the materials used in its design may result in water quality that falls outside the ranges defined in the project specifications.

Table 9. Water Quality Criteria (as defined by GSA)

Test	Acceptable	Baseline	Testing
T alkalinity (ppm)	100 – 1000	448	637
pH	7.3 – 9.0	8.6	8.7
CoC	>2	2.8	4.2
Bacteria Count (cfu)	<80,000	3,370	See Note
Calcium Hardness (ppm)	<500	599	743
Copper Corrosion rate (mpy)	<0.2	<0.1	0.25
Mild Steel Corrosion Rate (mpy)	<3	3.0	0.55

Note: During testing, there was an upset condition resulting in a high dip slide reading (bacteria). The water treatment contractor asserted that this is not uncommon and is resolved easily by shocking the system. This was not attributable to the AWT system.

Calcium hardness during testing is shown at above the acceptable limit but the baseline numbers were also above the recommended limit and tube scaling did not occur.

Cost Effectiveness

At the site load and local utility rate of $12.59/kgal, payback was 7.5 years. The measured 1.6 million ton hour annual load at the testbed was lower than the expected target load of 3 million ton hours due to inaccurate data provided by the site. Assuming the target load and GSA average water costs of $16.76 per kgal, the simple payback period drops to 2.6 years.

Additionally, the AWT system comes with an integral side-stream filtration system. This function is an added benefit that was not assessed during the testing but could provide better overall operations and could displace the need and costs for a sidestream filtration system at some sites. This value was not assessed and the size, operation, or robustness of the SSF system was not evaluated. Sites with high levels of suspended solids would need to work with the vendor to understand the applicability of this aspect of the technology.

Economically, Section III.C. looks at the costs for water at various regions and estimates the cost savings using these costs. The calculations for savings are based on the test site where the CoC went from 2.8 to 4.2. Based on variations in local water quality, sites could achieve a higher CoC and savings could increase substantially depending upon the final CoC value.

B. QUALITATIVE RESULTS

Quantitative results are discussed below relative to the objectives set out at the start of the evaluation and are summarized in Table 10 below.

Table 10. Qualitative Objectives and Results

Qualitative Objectives	Success Criteria	Metrics & Data	M&V Results
Ease of Installation	Interview with installer. Time required to install and configure.	< 5 days to install and commission one cooling tower	**Met -** Technology has a small footprint and is skid mounted.
Corrosion Monitoring	Continuous Electronic Corrosion monitoring for copper and mild steel using electrical resistance between probe points.	System is alarmed when the cooling tower water reaches a corrosive threshold using pH and conductivity monitors. Verified independently with plant meters for pH and conductivity.	**Met -** There were no corrosion excursions on the Aqualogix system and therefore no alarms were seen.
Operability	Interview with O&M staff.	Facility operators have no issues with technology	**Met -** No issues were reported by the site staff.
Site Safety	Chemicals	No hazardous chemicals used by the Aqualogix Lite system.	**Met -** No additional chemicals used except for salt. Loading sacks of salt into a hopper did not constitute a health issue.

Building staff were interviewed after the testing was completed to understand any qualitative changes in operational or maintenance issues. Comments for relevant areas are shown below.

Ease of Installation

The AWT system consists of a skid with a small footprint. Setting the skid, wiring and plumbing were straightforward. The installation is separate from the main cooling system only treating a portion of the flow. If the skid can be located close to the cooling water supply and return piping, the slip stream piping runs are short. The ties into the cooling water systems do not take much time or expense. For the Lloyd D. George Courthouse, the skid footprint was about 40 inches square with a height of about 91 inches. The skid weighs about 1,275 lbs dry (1,625 lbs operating weight). Most buildings are capable of handling equipment of this size without issue. The target goal was to complete the installation in less than 5 days. The installation was much less—at around 2 days—although there was some existing piping in place that made the installation easier. The implementation of the technology including installation and commissioning was satisfactory.

From a logistical standpoint, this system is easily deployed, installed, and operated. The technology fits onto a small footprint skid that can be set in place, installed and commissioned in a short period of time. Piping to and from the skid is the hardest cost to predict although the skid blowdown just needs a nearby drain location for discharge. Makeup water to the skid from city water will depend upon the location of the skid relative to a local tie-in point.

Ability to Monitor Corrosive Cooling Water Conditions

The AWT corrosion monitoring system is composed of monitoring, alarms, and measurement probes. Continuous Electronic Corrosion Monitoring is the measurement of resistance between the positive and negative points of an immersed measurement probe. This resistance is translated into a corrosion rate that is sampled and continuously trended to provide analysis for both preventative and predictive maintenance actions to occur. Installation of this monitoring equipment on installed systems provides a tool to reduce unexpected water side failures in heat exchangers, associated with chiller equipment

The AWT corrosion monitoring system comprises of:

- Continuous corrosion monitoring system for both copper and mild steel
- pH monitoring
- Conductivity monitoring

The system trends the key parameters of PH, conductivity and corrosion, and alarms based on user set points. Closed cooling water loop systems are susceptible to corrosion. Typical treatment practices for closed loop heating and cooling water systems employ standard water chemistry with monthly testing and corrosion coupons. For the purpose of this evaluation, corrosion monitoring is only being performed on the open loop condenser water system using an linear polarization resistance (LPR) instrument.

Continuous monitoring of open and closed loop systems would allow building operators to control corrosion mitigation programs using instantaneous measurement of the existing corrosion rate. The ability to identify corrosion in real time would allow for water chemistry treatment to be adjusted in time to prevent excessive corrosion.

The AWT system uses LPR to determine the rate of corrosion. The polarization resistance test method involves interaction with the electrochemical corrosion mechanism of metals in electrolytes to measure the instantaneous corrosion rate. Water monitoring was done using existing pH, ORP, and conductivity measurements. These values were taken simultaneously with the AWT monitoring system to better understand its effectiveness.

The AWT system also evaluates other operating parameters and signals an alarm if they are out of ranges preset prior to the testing. These measurements were independently verified.

Operability

Overall operation

Care of the water system was overseen by a chemical company with a representative that visits the site to test the water and make any necessary changes to the water treatment system. The site reported that the AWT equipment did not present any difficult operational issues. No additional labor costs for cleaning the cooling tower were incurred. The condensers have not been reopened since the testing was completed so the conditions of the tubes with respect to scale or other types of fouling have not been assessed at this point.

Cooling Tower Condition (overall cleanliness)

The cooling tower conditions were assessed prior to the testing and personnel responsible for cleaning the fill were interviewed to understand if there is any increase or decrease in the amount of labor required to clean the fill. A decrease would be entered as a savings and any increase would be included as a maintenance cost. No additional scale was noticed nor was the difficulty in removing scale noted as an issue.

Input from the Facility Managers

In general, the site staff liked the AWT system. The team on site stated that the system had little impact to their day to day duties and as long as it saves water, it is deemed to be a positive. Minimal time was required other than loading salt occasionally and stopping by to look at the screen to see that it was operational. The technology was well received overall.

Site Safety

Site safety can be affected by several factors. With regards to the AWT system, no new safety hazards were introduced other than the required loading of salt bags into a small hopper. This is not recognized as a signification safety issue.

C. COST-EFFECTIVENESS

The primary savings on the project were projected to be water savings. No reduction in cleaning labor costs were identified during the testing. The cooling towers were not more difficult to clean nor required more frequent cleaning but there were no reductions in either metric.

The installed cost of the AWT system equipment was $37,512. The cost breakdown is shown below.

Table 11. Installed Cost Breakdown

Test	Cost	Notes
Aqualogix Lite (200-1,000 ton load)	$26,543	Base unit only. No remote monitoring or pH, corrosion, ORP).
On-site training	$1,473	Travel, 4 hours classroom, 4 hours field instruction.
Shipping	$2,000	Estimated
Actual installation costs	$5,700	Actual costs incurred at Las Vegas site
Cost adder to account for pre-existing piping	$2,655	Piping and pipe taps were pre-existing due to another test system using this location.
TOTAL INSTALLED COST	**$38,371**	

The cost of water and the overall water savings were added to Table 11 along with the other relevant cost factors to develop a simple payback period in years. While the average cost of water at the site is $12.59 per kgal, the average water cost across GSA regions is $16.76 per kgal. Additionally, the average water costs for GSA regions has increased by 41% between 2014 and 2017. These higher costs and substantially reduce the payback periods for the technology.

The unit price was for a size that can handle a water system with a chiller water load between 200 tons and 1,000 tons. Discounted pricing was quoted for a system supplied to GSA and may vary for other clients. A simple payback period was calculated for both water rates as shown below in Table 12.

Table 12 – Economic Assessment Worksheet

Description	Testbed	Target Load & GSA Utility Rates	Notes
COSTS			
Equipment cost for 200-1000 ton load ($)	$30,016	$30,016	Base unit only. No remote monitoring or pH, corrosion, ORP. Includes startup. Assumes $2,000 shipping and $1,473 for training.
Installation cost ($)	$8,355	$8,355	$5,700 at testbed. $2,655 added since skid piping was already in place on site
Annual maintenance increase ($)	$783	$783	$250 for annual calibration & salt receiving and loading; $533 for salt
Annual water savings (kgal)	528,673	983,273	Target load was 3 million annual ton-hours, testbed had 1.6 million annual ton-hours or 187-ton avg load.
Annual water cost savings ($)	$6,656	$16,480	Testbed water cost $12.59 kGal; GSA avg. water rate $16.76
Annual technology electricity use (kWh)	7,735	7,735	8,760 hours at 0.883 kW
Annual increase in electricity ($)	$774	$851	Testbed electricity cost $0.10/ kWh; GSA avg. electric rate $0.11
Total annual savings ($)	$5,100	$14,846	
Payback (years)	7.5	2.6	
SIR	2.0	5.8	

[1] Using current technology costs provided by vendor and installation costs.

[2] Equipment lifespan is 15 years.

If the load is increased to the initial target load the GSA average water costs of $16.76 per kgal is used, the simple payback period drops to 2.6 years.

Table 13, below shows the payback period sensitivity to water costs.

Table 13 – Payback Sensitivity to Water Costs

Simple Payback (years)

Cost of Water ($/kgal)	Simple Payback for Testbed (years)	Simple Payback for Target Load & GSA Utility Rates (years)
$6.00	23.8	9.0
$8.00	14.4	6.2
$10.00	10.3	4.7
$12.00	8.0	3.8
$14.00	6.6	3.2
$16.00	5.6	2.7
$16.76	5.3	2.6
$18.00	4.8	2.4
$20.00	4.3	2.1
$22.00	3.8	1.9
$24.00	3.4	1.7

IV. Summary Findings and Conclusions

A. OVERALL TECHNOLOGY ASSESSMENT AT DEMONSTRATION FACILITY

GSA installed the AWT system in the Lloyd D. George Courthouse building in Las Vegas, Nevada to test whether the technology could maintain adequate water quality while conserving water, saving energy, and reducing operating costs. The determination of adequate water quality was made based on a previously developed set of benchmarks.

The economics of the AWT system are shown in Tables 12 and 13 above. The AWT system showed water savings of 15.3%.

Calculating the water reduction based on chiller load (gals/ton-hr) provides a metric for comparison to other facilities. The evaporation portion can be calculated with the equation:

$$E = \frac{F \times Q}{\Delta H_{vap} \times 8.34\ lb/gal}$$

- E is the gallons of water evaporated
- F is a factor expressing the ratio of latent to sensible cooling (usually a value between 0.75 and 1, with a value of one dictating total latent cooling)
- Q is the cooling required by the tower (can be calculated using $\dot{m}C_p\Delta T$); and
- ΔH_{vap} is the latent heat of vaporization of water (approximately 1,044 Btu/lb at 86 F).

Baseline gal/ton hr = 2.135 gal/ton-hr

New gal/ton-hr = 1.807 gal/ton-hr

A key variable in the economic calculations is the installation cost. The costs for a GSA installation may be higher on the first installation than subsequent installations due to unfamiliarity with the system and the nuances associated with the install. The costs for this installation totaled $38,371.

B. LESSONS LEARNED AND BEST PRACTICES

The installation of the AWT system only required a small footprint and a simple tie-in process. Since the installation and the removal of the technology are not invasive to the balance of the system, risk is largely mitigated. For the AWT system, the water treatment system can be valved out and removed at any time. The risk is then limited to the capital outlay and the technology can be installed on a trial basis and removed if performance is not per the guarantee.

The AWT system utilized a linear polarization resistance electrochemical method for measuring the corrosion rate in real time. The results of the measurements were very low. Mild steel corrosion rates averaged 0.55 mils per year and copper corrosion rates averaged 0.25 mils per year. Rates under 1.0 mils per year for mild steel is considered to be excellent. A rate of 0.25 mils per year for copper is considered to be very good.

C. DEPLOYMENT RECOMMENDATIONS

Cooling tower performance depends on a variety of factors, many of which are location-specific. Variables such as ambient air quality are specific to the site location and tower location on the site (*e.g*. airborne particulate matter), and seasonal changes have the potential to affect the observed operation of each technology evaluated. These factors can contribute to biological growth or mineral deposits that require additional chemicals.

Given that cooling tower performance is a function of wet bulb temperature, cooling tower performance and the amount of cooling delivered for each technology will also vary by site. Sites in dry climates with low wet bulb design temperatures are favorable for evaporative cooling systems. Variability in technology performance may also be a function of the type of cooling tower being used. The footprint of a given technology may vary with respect to the cooling tower size, and may impact the feasibility of its installation.

As important as the quantity of water used is the cost of water at the facility. Water cost savings is equal to the gallons saved times the cost per gallon. Areas with high water costs are of special interest.

Potable water quality is highly variable across the United States. The performance of these technologies is a function of the quality of influent water that is treated. Locations with high hardness, pH or total dissolved solids values typically have higher water and chemical usages. These are the sites that also have the greatest opportunity for savings. The AWT system is well suited for both retrofit and new construction applications.

Rebate opportunities may be available through local water utilities to implement water conserving technologies. The availability of these financial incentives can make the technology implementation even more cost-effective.

Market Potential Within the GSA Portfolio

The first step in evaluation of further deployment of an AWT technology is the identification of buildings in the GSA portfolio that have water-cooled chillers. These are typically larger buildings with high cooling loads that benefit from the improved efficiency of water-cooled chiller plants (and where the higher initial cost of a chiller plant is warranted due to higher loads).

The next step in site selection is identifying sites where the AWT technology will perform well economically. To assist GSA in identifying sites that have high potential water and/or cost savings, NREL previously used the whole-building modeling software EnergyPlus™ to model water savings potential in an NREL/GSA GPG report entitled *Alternative Water Treatment Technologies for Cooling Tower Applications*. The "Large Office" building model was selected from the Commercial Reference Buildings that are developed and maintained by the U.S. Department of Energy and NREL (DOE n.d.). The Commercial Reference Buildings are a set of EnergyPlus building models that represent typical building types and constructions and include climate-specific models (per building type) for each of the sixteen different ASHRAE climate zones. For the modeling analysis included in this report, the "post-1980" construction model was used.

The large office building model is a 498,588 ft^2 office building that is cooled via a water-cooled chiller. The standard cooling tower model in EnergyPlus defaults to blowdown operation that maintains a CoC of 3.0. To evaluate the potential impact of AWT in the national GSA building portfolio, the large office building model was simulated in 16 different U.S. cities, one representative city for each of the 16 ASHRAE climate zones. For each climate zone, the model was run for two scenarios: (1) with the cooling tower set to maintain a CoC 2.81 to match the baseline for this study and (2) with the cooling tower set to maintain a CoC of 4.2 to match the performance of this AWT post retrofit. Figure 16 shows the annual evaporation (in thousands of gallons water) and the annual water savings for a CoC of 4.2. The cities with larger numbers of cooling degree days and more arid climates show the greatest water savings (delta between light grey bars).

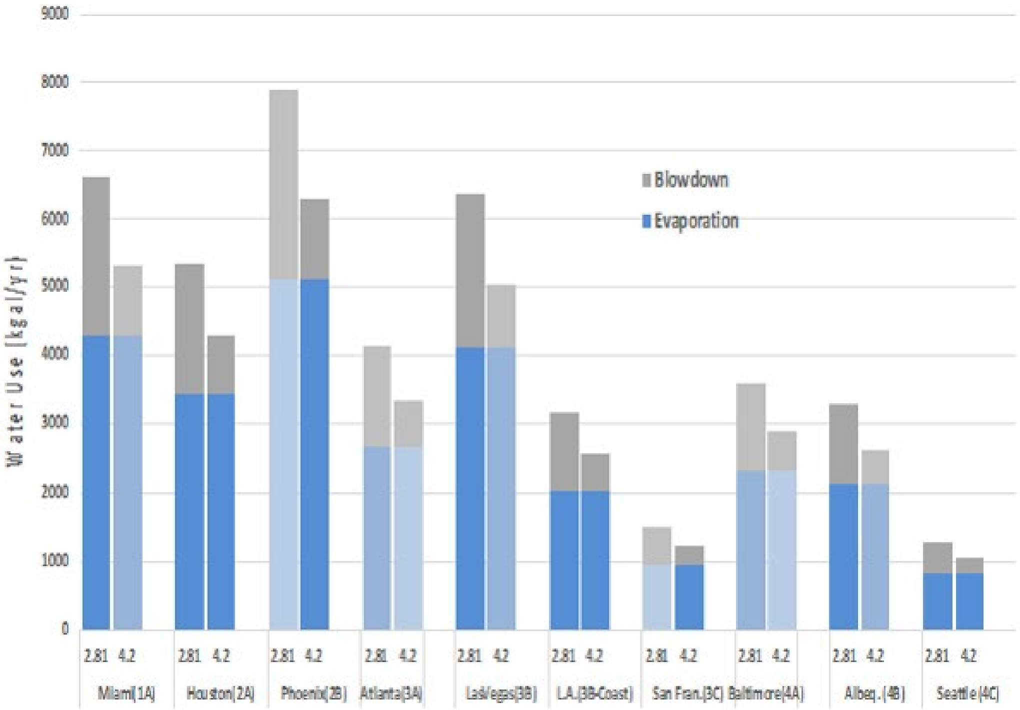


Figure 16: Modeled water evaporation and blowdown savings across ASHRAE Climate Zones

The water savings numbers were then translated into annual cost savings using site specific water rates. Combined water and wastewater rates were obtained from local water utilities for each city, assuming each site is on a 6-in. water line and uses more than 200,000 gallons per month. The annual water savings for each location were multiplied by the combined water rate for each city. The results from this analysis are presented in Figure 17, below.

The wide variation in water costs between the different cities results in a significantly different picture in cost savings than is seen in water savings. Cities with high water rates (such as Atlanta, Georgia) generate the largest annual cost savings despite not having the largest total water savings. Table 14 gives the water rates used in this evaluation (current as of May 2018).

Table 14: Combined Water and Wastewater Rates for Sample Cities across Each of the 16 - ASHRAE Climate Zones

Location (Climate Zone)	Combined Water and Wastewater Rate ($/kgal)	Location (Climate Zone)	Combined Water and Wastewater Rate ($/kgal)
Miami (1A)	13.62	**Albuquerque (4B)**	4.98
Houston (2A)	10.38	**Seattle (4C)**	25.18
Phoenix (2B)	7.76	**Chicago (5A)**	7.76
Atlanta (3A)	29.12	**Boulder (5B)**	9.32
Las Vegas (3B)	8.25	**Minneapolis (6A)**	9.98
Los Angeles (3B-Coast)	8.88	**Helena (6B)**	8.30
San Francisco (3C)	24.01	**Duluth (7A)**	13.51
Baltimore (4A)	12.30	**Fairbanks (8A)**	22.07

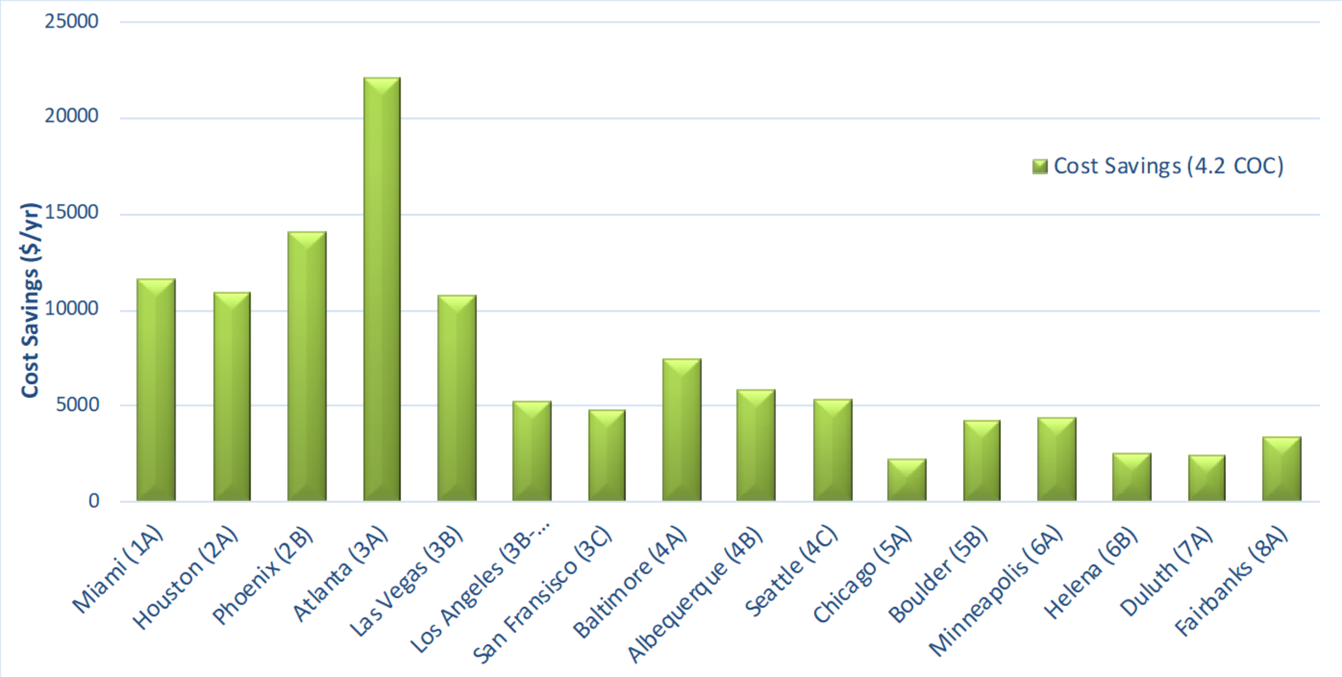


Figure 17: Estimated yearly cost savings by Climate Zone

To gain an appreciation of the market potential for GSA, approximate system costs were used to calculate a SIR for each city. Note that this calculation assumes that the annual operating costs associated with these systems are the same after the installation as they were with the original system. The ratios denoted here are rough estimates, considering the assumptions that the original system was operating at a CoC of 2.8, the new system would achieve a CoC of 4.2, and that the annual operating costs remain the same pre- and post-installation, yet they give a feeling for the critical variables driving economic viability of the system in various U.S. locations. The SIRs for a high installed cost assumption ($65,000) and a low-cost assumption ($45,000) are shown in Figure 18 and Figure 19, respectively. The size of the cooling towers in the Energy Plus model ranged from around 1,800 to 2,500 tons and the AWT's capital costs were scaled up for these larger systems. The figures show the modeled SIRs for a given water and wastewater combined rate across various climate zones. The SIR calculation assumes a 15-year project life with $783/yr in O&M cost increase and $774 in onsite electrical costs that are based on the system drawing 883 watts 24 hours a day, 7 days a week, 365 days per year at the local electric rates.

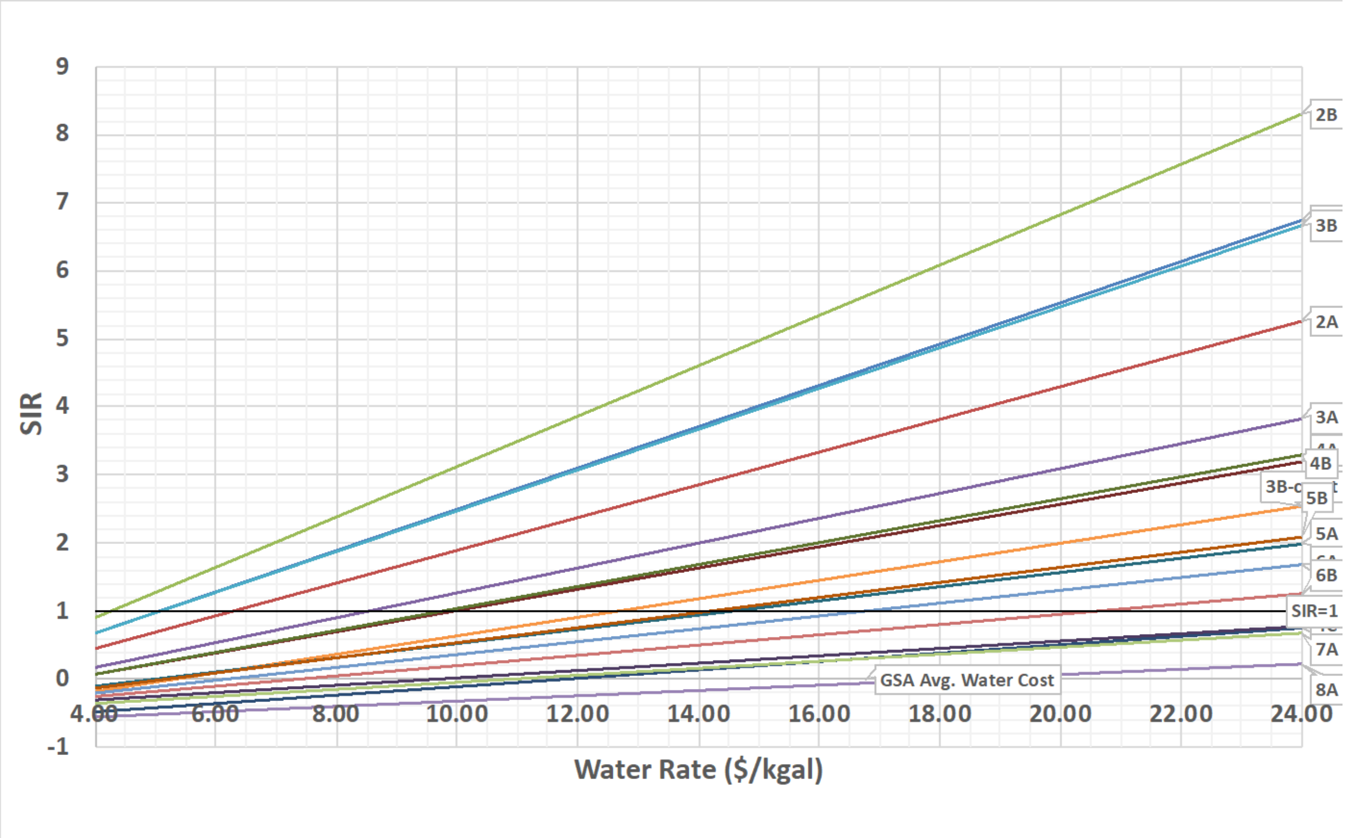


Figure 18. SIR for same system in evaluated Climate Zones for various water rates: High-cost scenario

For the high-cost scenario, Phoenix, Arizona, Las Vegas, Nevada, Miami, Florida, Houston, Texas, Atlanta, Georgia and Albuquerque, New Mexico all had SIRs >1 at combined water and wastewater rates above $10/kgal. The results for the low cost scenario are provided in Figure 19.

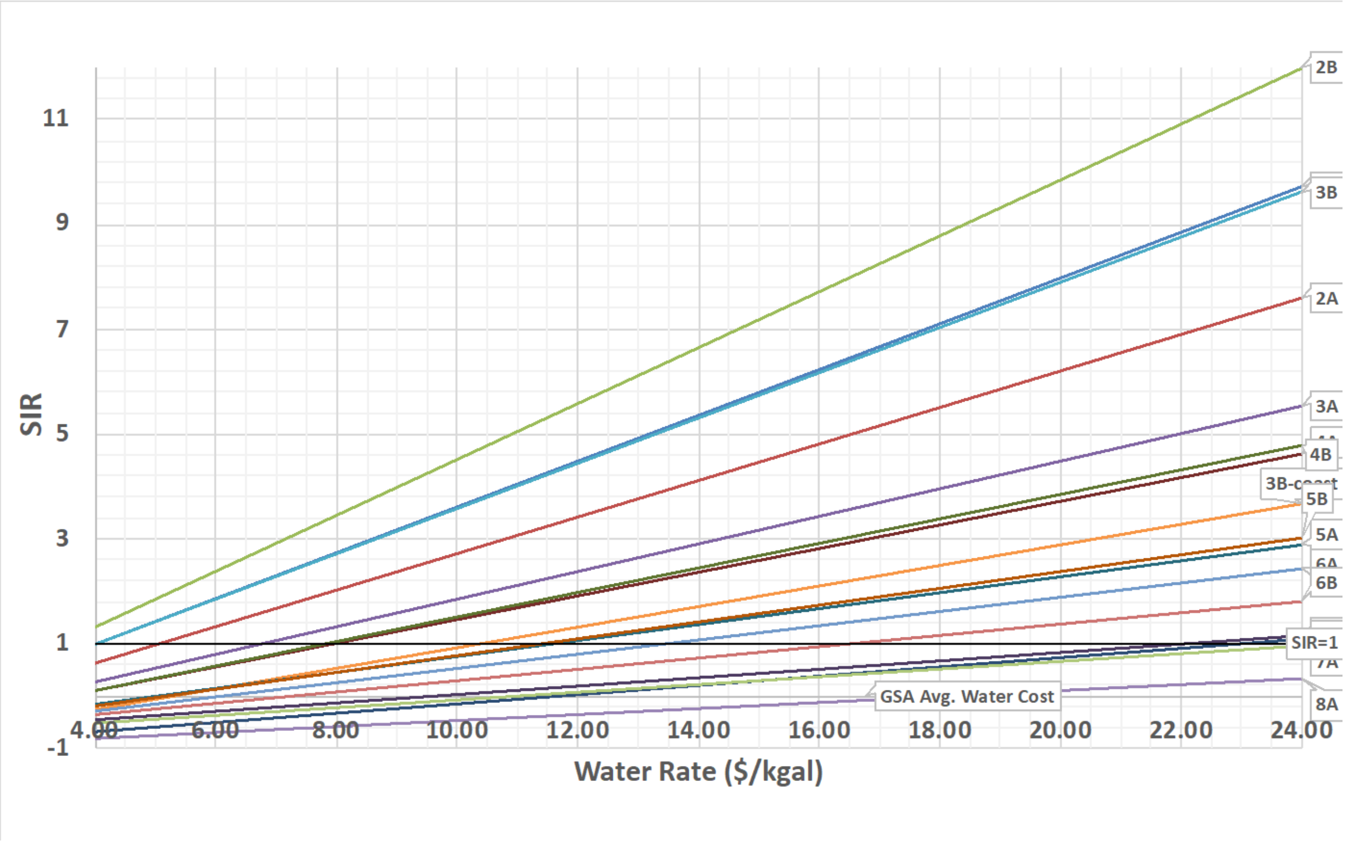


Figure 19: Savings-to-Investment Ratio for Same System in Evaluated Climate Zones for Various Water Rates: Low-Cost Scenario

For the low-cost scenario, the AWT is life cycle cost-effective (SIR>1) in all climate zones except Fairbanks, AK, Duluth, MN, Helena, MT and Seattle, WA.

It should be noted that this system does not require any modification to existing chemical contracts which allows for a simpler implementation. Additionally, the AWT system includes sidestream filtration that could be an additional cost savings for sites that are considering this option.

The vendor provided a worksheet that estimates the savings of a 3 million ton-hr per year system for various locations and water rates. This table has not been vetted and is for informational purposes only. The table is included as Appendix E.

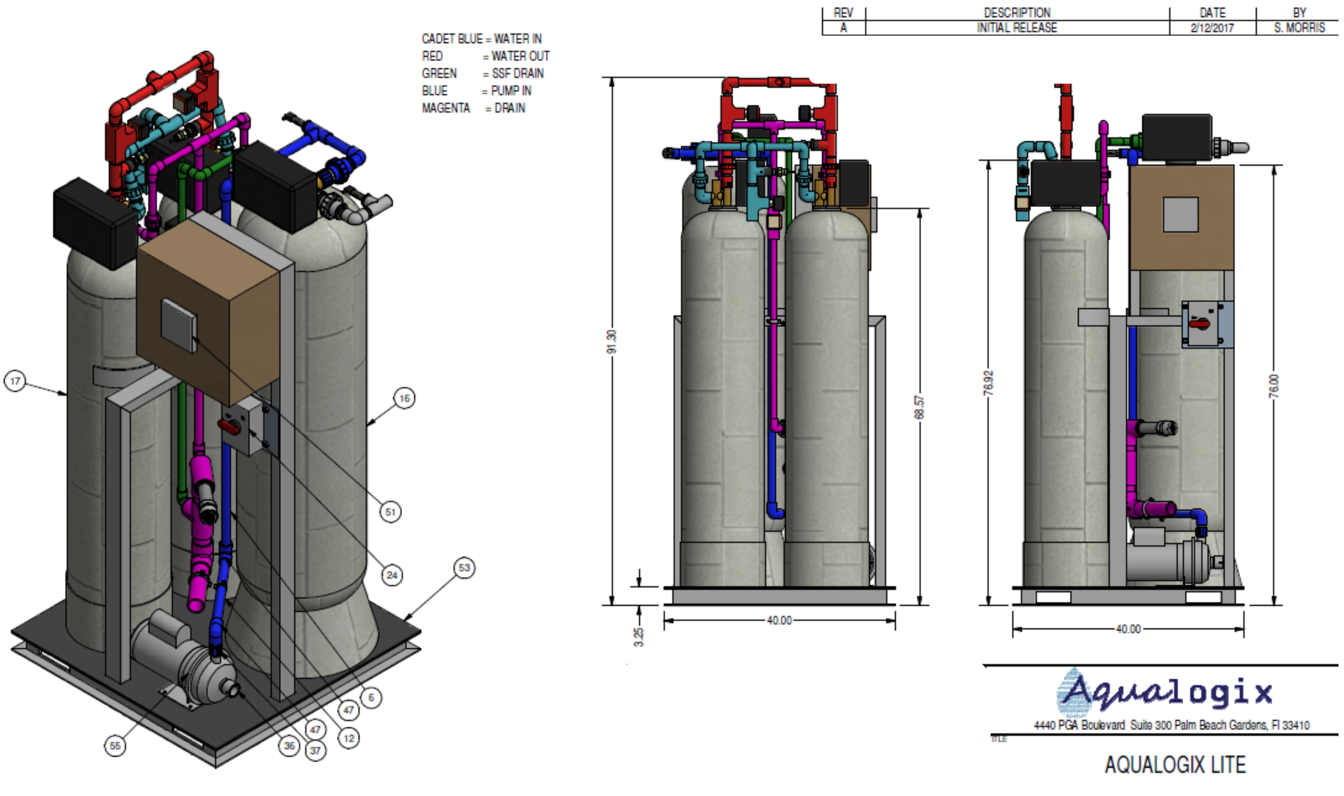
V. Appendices

A. ECONOMIC ANALYSIS

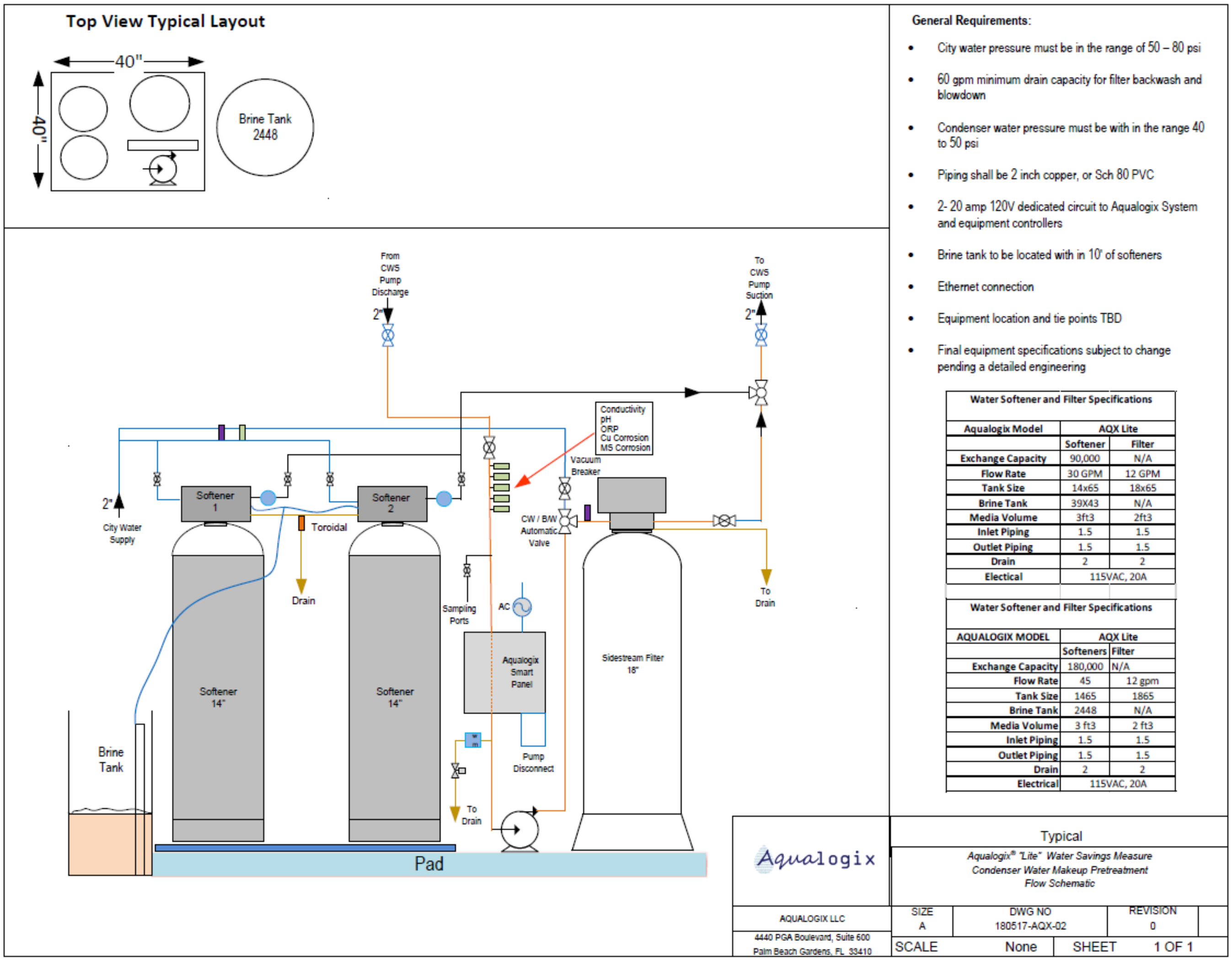
The economic evaluation was based on the annual savings, the initial cost of the technology and the yearly O&M costs. Using these values, the simple payback period (in years) was calculated.

Cooling tower water use is made up of three components: evaporation, blowdown and drift. The evaporation component provides the cooling to the chiller system and is not a function of the water treatment technology, but rather of the cooling required by the building. The drift component is determined by the physical characteristics of the cooling tower and the flow rate through the tower. Due to the fact that the cooling towers (and their associated pumps) were not altered during the water treatment technology installations, the drift component should not have changed from pre-to post-installation; therefore, the water savings calculated in this report should be direct reduction in blowdown due to the ability to increase the CoC achieved in the condenser loop.

B. MANUFACTURER CUT SHEET



(Credit: Aqualogix)



General Requirements:

- City water pressure must be in the range of 50 – 80 psi
- 60 gpm minimum drain capacity for filter backwash and blowdown
- Condenser water pressure must be with in the range 40 to 50 psi
- Piping shall be 2 inch copper, or Sch 80 PVC
- 2- 20 amp 120V dedicated circuit to Aqualogix System and equipment controllers
- Brine tank to be located with in 10' of softeners
- Ethernet connection
- Equipment location and tie points TBD
- Final equipment specifications subject to change pending a detailed engineering

Water Softener and Filter Specifications

Aqualogix Model	**AQX Lite**	
	Softener	**Filter**
Exchange Capacity	90,000	N/A
Flow Rate	30 GPM	12 GPM
Tank Size	14x65	18x65
Brine Tank	39X43	N/A
Media Volume	3ft3	2ft3
Inlet Piping	1.5	1.5
Outlet Piping	1.5	1.5
Drain	2	2
Electical	115VAC, 20A	

Water Softener and Filter Specifications

AQUALOGIX MODEL	**AQX Lite**	
	Softeners	**Filter**
Exchange Capacity	180,000	N/A
Flow Rate	45	12 gpm
Tank Size	1465	1865
Brine Tank	2448	N/A
Media Volume	3 ft3	2 ft3
Inlet Piping	1.5	1.5
Outlet Piping	1.5	1.5
Drain	2	2
Electrical	115VAC, 20A	

Aqualogix

Typical

Aqualogix® "Lite" Water Savings Measure
Condenser Water Makeup Pretreatment
Flow Schematic

AQUALOGIX LLC
4440 PGA Boulevard, Suite 600
Palm Beach Gardens, FL 33410

SIZE	DWG NO	REVISION
A	180517-AQX-02	0

SCALE	None	SHEET	1 OF 1

(Credit: Aqualogix)

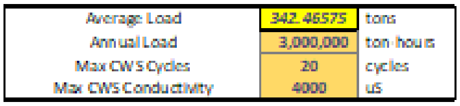
C. IT SECURITY AND CONTINUITY OF CONNECTIVITY

No issues with continuity of connectivity were encountered. The system can operate in a "stand alone" basis without external connectivity. The provision for a secure connection could allow the manufacturer to monitor its system for any anomalies and to modify system settings to provide better performance between maintenance visits. The vendor has deployed a controller for integration of their unit into the site's BACnet BAS. This is an issue for each GSA building to consider.

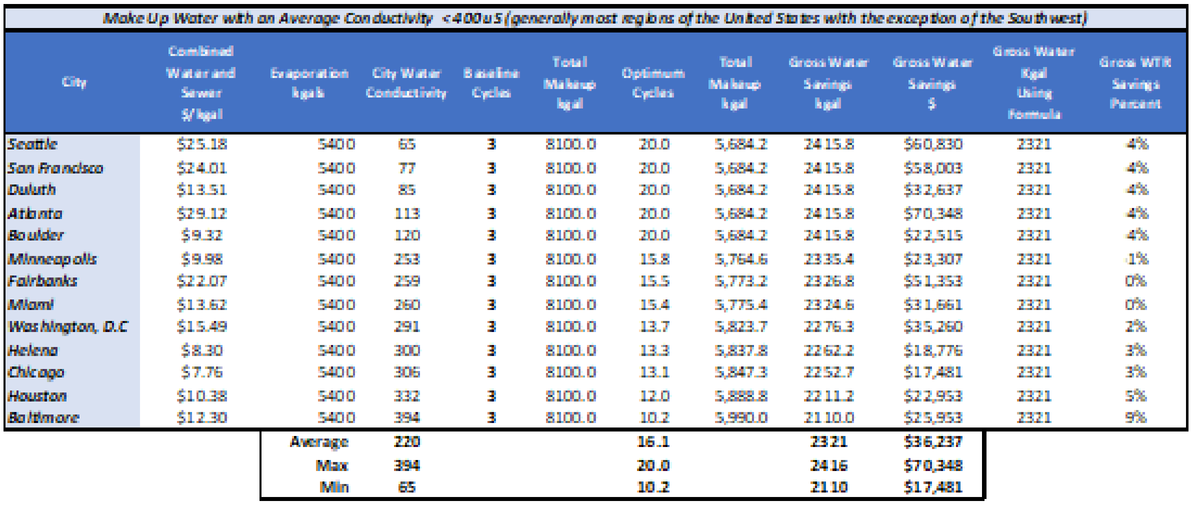
D. TECHNOLOGY MARKET READINESS

The AWT system is commercially available and distribution and installation channels are in place. There are numerous installations of the AWT technology in the United States varying in size and application. Fabrication of these systems is relatively simple and the lead times for new installations is not expected to be lengthy.

E. VENDOR ESTIMATE FOR DEPLOYMENT SAVINGS



Average Load	342.46575	tons
Annual Load	3,000,000	ton hours
Max CWS Cycles	20	cycles
Max CWS Conductivity	4000	uS

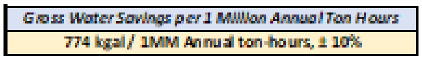


Make Up Water with an Average Conductivity <400uS (generally most regions of the United States with the exception of the Southwest)

City	Combined Water and Sewer $/kgal	Evaporation kgals	City Water Conductivity	Baseline Cycles	Total Makeup kgal	Optimum Cycles	Total Makeup kgal	Gross Water Savings kgal	Gross Water Savings $	Gross Water Kgal Using Formula	Gross WTR Savings Percent
Seattle	$25.18	5400	65	3	8100.0	20.0	5,684.2	2415.8	$60,830	2321	4%
San Francisco	$24.01	5400	77	3	8100.0	20.0	5,684.2	2415.8	$58,003	2321	4%
Duluth	$13.51	5400	85	3	8100.0	20.0	5,684.2	2415.8	$32,637	2321	4%
Atlanta	$29.12	5400	113	3	8100.0	20.0	5,684.2	2415.8	$70,348	2321	4%
Boulder	$9.32	5400	120	3	8100.0	20.0	5,684.2	2415.8	$22,515	2321	4%
Minneapolis	$9.98	5400	253	3	8100.0	15.8	5,764.6	2335.4	$23,307	2321	1%
Fairbanks	$22.07	5400	259	3	8100.0	15.5	5,773.2	2326.8	$51,353	2321	0%
Miami	$13.62	5400	260	3	8100.0	15.4	5,775.4	2324.6	$31,661	2321	0%
Washington, D.C	$15.49	5400	291	3	8100.0	13.7	5,823.7	2276.3	$35,260	2321	2%
Helena	$8.30	5400	300	3	8100.0	13.3	5,837.8	2262.2	$18,776	2321	3%
Chicago	$7.76	5400	306	3	8100.0	13.1	5,847.3	2252.7	$17,481	2321	3%
Houston	$10.38	5400	332	3	8100.0	12.0	5,888.8	2211.2	$22,953	2321	5%
Baltimore	$12.30	5400	394	3	8100.0	10.2	5,990.0	2110.0	$25,953	2321	9%
		Average	**220**			**16.1**		**2321**	**$36,237**		
		Max	**394**			**20.0**		**2416**	**$70,348**		
		Min	**65**			**10.2**		**2110**	**$17,481**		

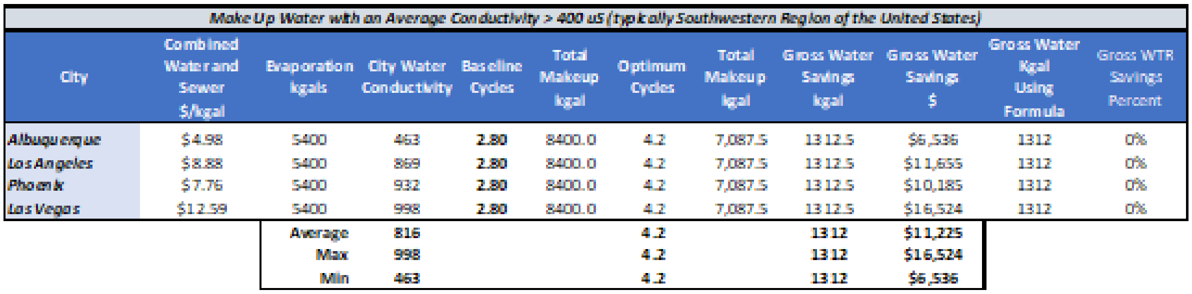
Note 1: GSA Baseline Cycles of Concentration (CoC) is 3.0. it is understood that there are regional water qualities that allow for a CoC greater than this limit, without the need for par

Note 2: Optimum CoC is only achievable through partial softening or demineralization processes due to the make up of the water quality



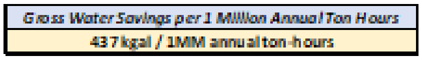
Gross Water Savings per 1 Million Annual Ton Hours
774 kgal / 1MM Annual ton-hours, ± 10%

Average Load	342.47	tons
Annual Load	3,000,000	ton hours
Max CWS Cycles	8	cycles
Max CWS Conductivity	4200	uS

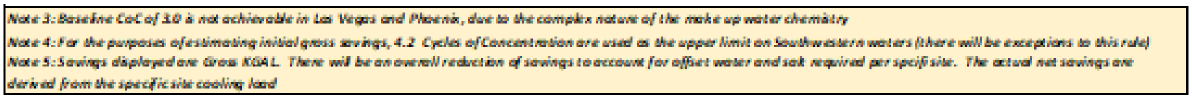


Make Up Water with an Average Conductivity > 400 uS (typically Southwestern Region of the United States)

City	Combined Water and Sewer $/kgal	Evaporation kgals	City Water Conductivity	Baseline Cycles	Total Makeup kgal	Optimum Cycles	Total Makeup kgal	Gross Water Savings kgal	Gross Water Savings $	Gross Water Kgal Using Formula	Gross WTR Savings Percent
Albuquerque	$4.98	5400	463	**2.80**	8400.0	4.2	7,087.5	1312.5	$6,536	1312	0%
Los Angeles	$8.88	5400	869	**2.80**	8400.0	4.2	7,087.5	1312.5	$11,655	1312	0%
Phoenix	$7.76	5400	932	**2.80**	8400.0	4.2	7,087.5	1312.5	$10,185	1312	0%
Las Vegas	$12.59	5400	998	**2.80**	8400.0	4.2	7,087.5	1312.5	$16,524	1312	0%
		Average	**816**			**4.2**		**1312**	**$11,225**		
		Max	**998**			**4.2**		**1312**	**$16,524**		
		Min	**463**			**4.2**		**1312**	**$6,536**		



Gross Water Savings per 1 Million Annual Ton Hours
437 kgal / 1MM annual ton-hours



Note 3: Baseline CoC of 3.0 is not achievable in Las Vegas and Phoenix, due to the complex nature of the make up water chemistry

Note 4: For the purposes of estimating initial gross savings, 4.2 Cycles of Concentration are used as the upper limit on Southwestern waters (there will be exceptions to this rule)

Note 5: Savings displayed are Gross KGAL. There will be an overall reduction of savings to account for offset water and salt required per specific site. The actual net savings are derived from the specific site cooling load