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Improving Cooling Tower Chemistry Control And Cost Savings Through Automation

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IMPROVING COOLING TOWER CHEMISTRY CONTROL AND COST SAVINGS THROUGH AUTOMATION

by

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ABSTRACT

Proper chemistry control of cooling towers reduces corrosion, biological growth, and precipitation of solids. Therefore, improving control can lead to increased equipment life, operating efficiency, and safety. Chemistry of cooling towers is highly dependent on loading, weather, and time. As such, cooling tower chemistry varies day to day and even hour to hour, requiring either continuous controls or large operating bands. Through automation, 24/7 monitoring and control can be achieved, allowing for deliberate operation within tight operating bands. As a direct result of automation water consumption has been reduced by 9.1 million gallons per year, CL-49 use has been reduced by 21.2%, and chemistry bands have been drastically narrowed. Indirectly it is expected that both corrosion rates and biological growth will be reduced, due to the improved chemistry.

PREFACE

This project was originally identified as an opportunity for cost savings and continuous improvement. Prior to initiating the project, it was known that the existing sample panel had some form of automatic control capabilities, so the intent of this project was to capitalize on those capabilities. During an evaluation and review of the systems documentation and capabilities, a design from 2012 was discovered that accomplished the project goals. However, it was found that the design was not implemented due to excessive cost and impact, requiring prolonged down time and extensive modification to the existing cooling tower system. Due to ongoing budgetary limitations, it was decided that a redesign focused on minimizing cost and impact was necessary.

The original scope was further extended beyond the cost-effective design modification to include system control improvement. Goals of minimizing water consumption, man hours, corrosion, and biological growth were set. These goals were prioritized on the basis of health and safety first, followed by environmental safety and cost savings. Other aims included reducing water consumption, tightening the Cl operating band, and generally improve control of operating chemistry.

Opportunities beyond the scope of this project that were identified for future implementation, including experimentation with biological growth control to reduce growth of algae and the bacterium *Legionella*. Current biological growth is excessive and unresponsive to current means of control. Potential solutions could include lowering

the pH and precipitating phosphate out of the cooling water. During future testing, the automatic control system implemented in this project could limit the effects of variables, allowing for more conclusive testing of these potential solutions. If one of these potential solutions is proven effective, the automated system could provide a means of control for both pH and phosphate precipitation. Due to *Legionella's* potential risk to community health and safety, it will be important that every effort is made to control and minimize these inherent risks in the future.

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LIST OF SYMBOLS

BD	Blowdown, gpm
CoC	Cycles of concentration
E	Evaporation, gpm
F	Evaporation Factor
MU	Makeup, gpm
RR	Recirculation rate, gpm
ΔT	Cooling Range, F

LIST OF ABBREVIATIONS

Cl.. Free Chlorine

CL-49 .... Halogen

CoC .... Cycles of Concentration

gpm .... Gallons per Minute

GUI .... Graphical User Interface

TDS .... Total Dissolved Solids

CHAPTER 1 SYSTEM CONFIGURATION

1.1 PHYSICAL DESCRIPTION

This project aims to improve the chemical control 120,000 Gal cooling water system. The primary system's purpose is to transfer thermal energy from a chill water loop to the atmosphere. The primary system components include a basin, four pumps, four heat exchangers, three cooling towers, and the required piping and valves. The basin holding approximately 100,000 gallons serves as a surge volume as well as a mixing basin for chemical addition. The four single speed centrifugal pumps maintain necessary driving force for circulation of loads ranging from no load to full load, based on configuration. The four heat exchangers are used as necessary depending on load requirements to transfer heat from the chill water system into the cooling water system. Three large cooling towers atomize warm water to allow efficient heat transfer to the atmosphere. The associated piping and valves provide the necessary flow paths for varying load configurations.

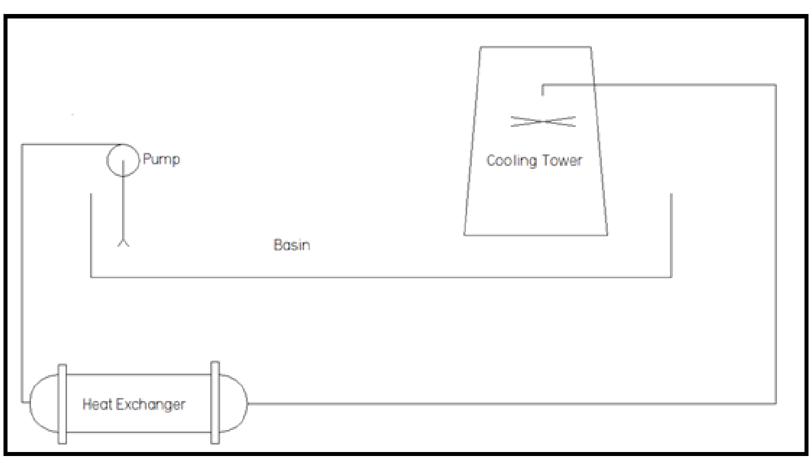

Figure 1.1. Simplified Primary System Single Line

In addition to the primary system, there exists a secondary system designed to monitor and maintain chemistry to support continued operation. This secondary system is comprised of a blowdown line, fill line, chemical addition line, and water monitoring line. The blowdown line provides a path for draining of the system and is connected to the discharge header of the basin pumps. The fill line is sourced from service water with an approximate conductivity of 80uS and is level-controlled using a ball float to maintain the basin at a constant level. The chemical addition line is a flex hose used to add CL-49 directly into the basin for mixing. The water monitoring line is Tee'd off from the blowdown line and is sent to a sample panel in an adjacent building where Total Dissolved Solids (TDS) and Free Chlorine (Cl) levels are monitored.

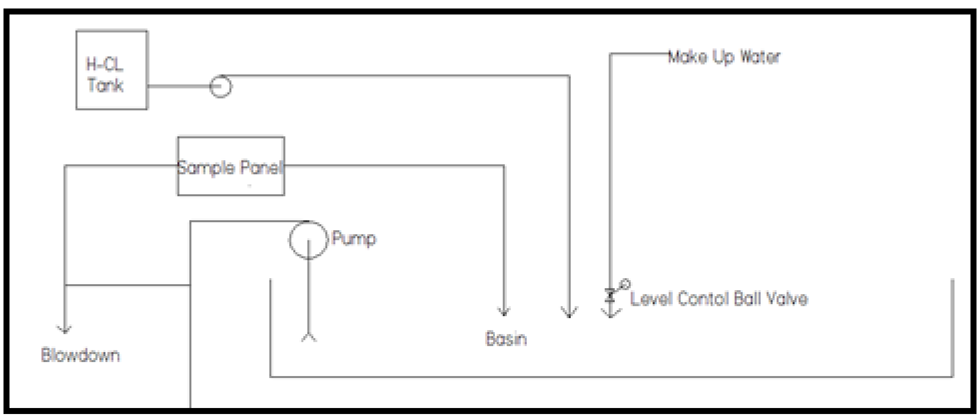

Figure 1.2. Simplified Secondary Systems

Chemistry control is extremely important to cooling tower operation due to concerns regarding precipitating solids, biological growth, and corrosion. These factors reduce overall system efficiency and shorten the lifespan of system components by reducing thermal efficiency of the heat exchangers, increasing head pressure of piping, and increasing wear of components. For these reasons, it is highly desirable to maintain control of these factors.

Due to the evaporative cooling process of the towers, water is constantly evaporating, resulting in an increase in TDS concentration. For a given water chemistry there is an effective limit to TDS that, if maintained below solids, will stay in solution. (1) If TDS exceeds these limits, solids will begin to precipitate which will then form deposits that impede flow and decrease thermal performance. To maintain below this limit, TDS concentration is controlled through blowdowns and fills. By removing water with a relatively high concentration and replacing with water with a low concentration, the total TDS is lowered. TDS is monitored by conductivity and which is read in units of uS. The conductivity of the sample is compared to the conductivity of the source make-up water. The resulting ratio of conductivity is referred to as Cycles of Concentration (CoC). By industry standards 3-12 CoC are normal (2).

Due to the open system configuration, biological growth is inevitable. This biological growth is primarily controlled through the addition of CL-49 which serves as a biocide. Other indirect methods of controlling biological growth include lowering TDS and lowering pH. TDS is controlled through blowdowns, increasing the volume of water blown down decreases the TDS of the system, which reduces vital nutrients for biological growth and reduces pH, resulting in increased effectiveness of the biocide agent. The source water is assumed to have a constant TDS level so that the decrease in system TDS results in a decrease in CoC.

In 2003, a Chemtreat WebMaster (WM1) Panel board was purchased and installed with the intent of providing automated chemistry control for the 120,000 gallon cooling tower. This panel was plumbed and powered to monitor Cl and TDS levels, but not for control purposes. The panel board is equipped with 5 relays capable of operating

pumps and solenoids. The panel has advanced programing options available to allow optimization of chemical addition and blowdown.

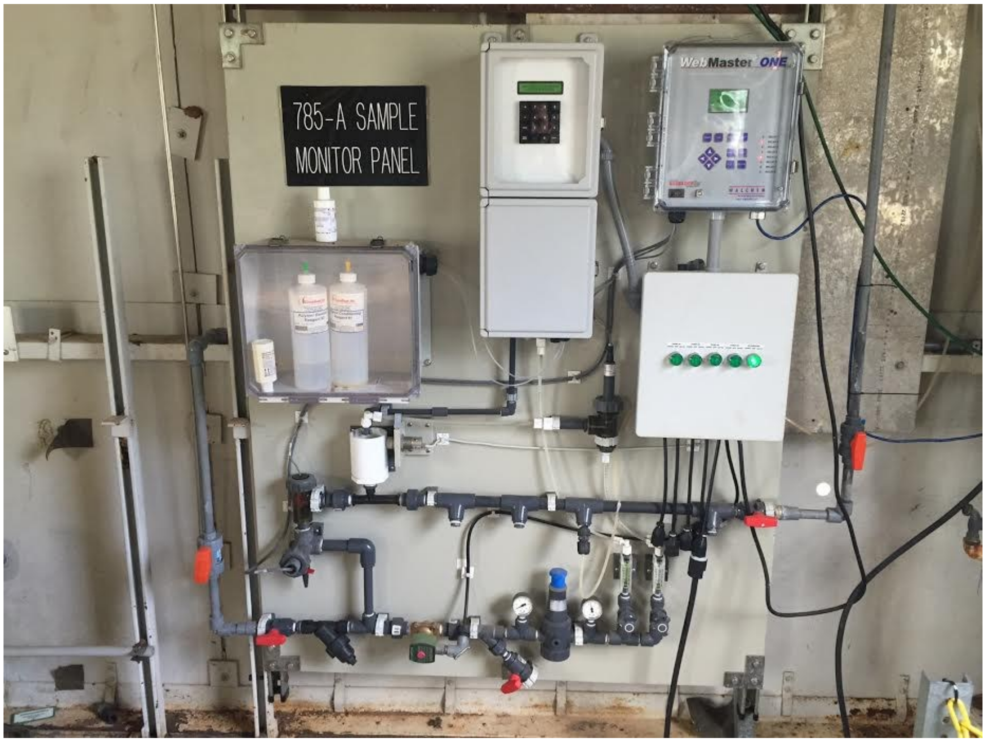

Figure 1.3. Chemtreat Sample Panel

1.2 SYSTEM OPERATION

Current system operation is done manually though a continuous blowdown and chemical addition. Operators conduct daily rounds on the system to monitor Cl and TDS with monthly rounds to monitor Legionella count.

A continuous blow down is achieved by a throttling a valve on the blowdown line. This throttling is periodically adjusted to control TDS. A continuous addition of CL-49 is achieved through a continuously ran metering button pump. The rate of chemical addition is varied to ensure Cl is available as a biocide.

Figure 1.4. Blowdown valve throttled

Figure 1.5. CL-49Metering Pump

1.3 SYSTEM AND OPERATIONAL DEFICIENCIES

Current continuous blowdown is not effectively monitored or controlled to regulate TDS. Currently blowdown valve throttling is infrequently adjusted to account for changing conditions.   Due to changing environmental conditions and customer need, the rate of flow, evaporation, and carry varies continuously. With the variance in flow, evaporation, and carry, and a continuous blowdown, the TDS varies with conductivity

ranging from 100-400uS. This large operating band results in excessive water waste and chemical loss.

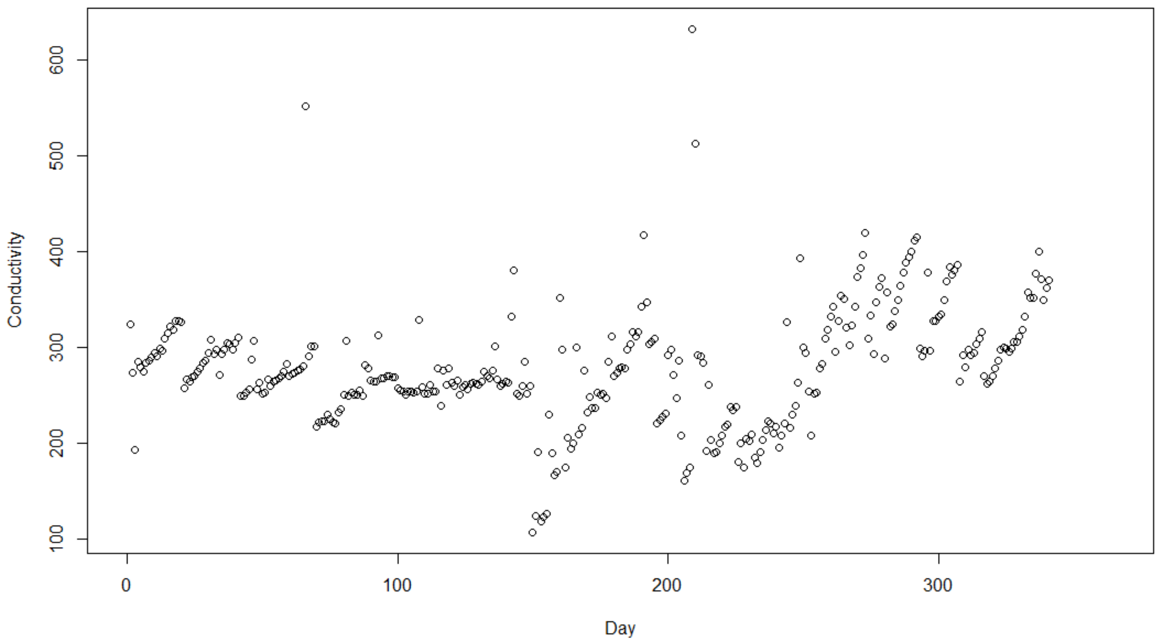

Figure 1.6. Operator logs for Conductivity over a twelve-month period.

Due to supply water's constant TDS, the variance in sample conductivity results in a variance in CoC. Shown in figure 1.7, the amount of water required to maintain a given CoC increases exponentially in response to a reduction of CoC. As a result, periods of time where CoC is operated at relatively low values have a significantly larger impact on water consumption. This means that the average TDS or CoC does not represent the average blowdown rate. In order to determine an average blowdown rate, a model of the probability of a given TDS needs to be used. This model will be further discussed in Chapter 3.

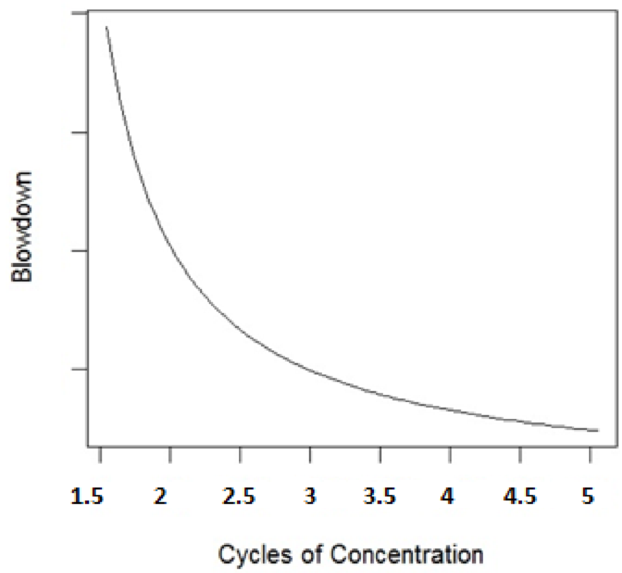

Figure 1.7. Cycles of Concentration with respect to required blowdown

Current manual control of CL-49 addition results in a variance in Cl ranging from 0 ppm to 1.7 ppm. While Cl is necessary to retard biological growth, excessive Cl increases corrosion rates. With a system spec of .25 - 1.0 ppm, current Cl control periodically falls short of, or alternately, exceeds these specs. This may be causing excessive corrosion and ineffective biological growth control (1).

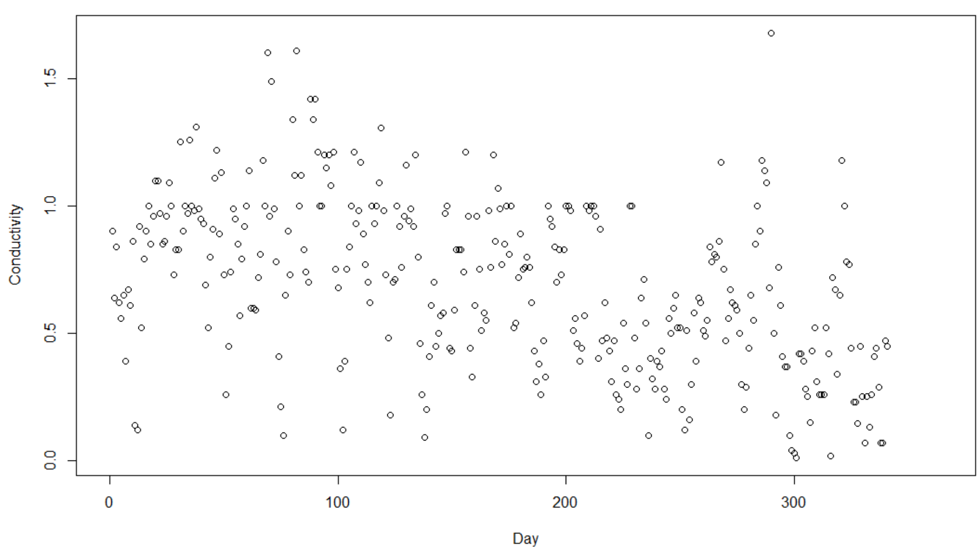

Figure 1.8. Operator logs for Free Chlorine over a twelve-month period

CHAPTER 2: DESIGN

2.1 DESIGN GOALS

Through automation of the cooling water auxiliary services, direct improvements to water consumption, chemical consumption, man hours, reliability, and corrosion control should be achieved. Automation should also indirectly improve Legionella control as well as establish a baseline for site-wide adoption of these controls.

The Current operating band allows for 100-400uS for conductivity (3), as seen in Figure 1.7, with returns on increasing cycles beyond 3.5 resulting in diminished linear improvements. With a maximum of five cycles based on concentration operating limits, the target is to maintain greater than 4.5 cycles at approximately 360uS. This target is based on maximizing water savings while remaining in current accepted limits. However, as a result of the relative increase in cycles of conductivity, the TDS and pH of the system tend to increase resulting in a potential increase in biological growth. If necessary to maintain acceptable biological growth control, the 4.5 cycle target may be reduced as necessary to balance water savings and biological growth.

Through automation, tight Cl controls will allow for efficient use of chemicals. Further chemical addition will be suspended prior to blowdowns and increased immediately following blowdowns. This will minimize CL-49 lost to blowdowns and maximize its life span in system. The goal is to maintain Cl in the 0.5 to 0.9 ppm range to ensure sufficient Cl and minimize corrosion.

Successful automation will directly reduce man hour needs to the minimum required to monitor the system and will improve system control. Daily and monthly rounds will be performed normally, but operators will no longer be expected to adjust system parameters. Once automation has been established and monitored, further investigation into periodicity of rounds to further reduce man hours can be done. Reliable automation allows for repeatable, sustainable and continuous control. Continuous monitoring of system parameters will allow for tight operating bands and deliberate control. Through tight controls of TDS and Cl, system corrosion will be minimized.

Current algae growth within the basin is unacceptable and has proven resistant to typical methods of control. A plan to add a phosphate precipitant to remove phosphate from solution to "starve" the algae of a vital food source is being reviewed. Lowering of pH through addition of an acid is also under review. Both precipitant and acid tests are outside the scope of this project. However, automated control of TDS and Cl could enable a more controlled testing of these methods of biological control.

2.2 MECHANICAL DESIGN

In order to meet the prescribed goals, a method for controlling TDS and Cl in a reliable manner proved essential. The revised design relied heavily on existing components and on maximizing unused functionality. As a result, a low cost, simple, and practical design was created. In order to control TDS and Cl, the blowdown and the Cl addition rates had to be controlled. The sample panel previously only took TDS and Cl measurements for operators' records. However, the Panel had the ability to be

configured for automating control. In an attempt to reduce cost, these existing control panel features were utilized.

On initial inspection of the panel, it was found to be equipped with 120V relays capable of programed operation. This lead to an initial design that required both a blowdown valve and Cl pump to cycle on and off at determined system boundary conditions. This allowed basic control of system parameters to mimic current operation on a continuous basis. Upon further investigation, it was discovered that with the addition of a 4-20mA control card the Panel could supply a 4-20mA signal based on measured readings. With 4-20mA control signals, it would be possible to control both a blowdown valve and CL-49 pump to a much greater degree.

The Existing CL-49 Pump previously was manually controlled by the operators who would increase or decrease cycle speed of the pump daily. In investigating the pump, it was found to have a native 4-20mA control capability. This feature was previously unused and would only require the corresponding 4-20mA control card for the panel and the associated wiring.

In investigating control valves for the blowdown, it was found that 4-20mA valves were significantly more expensive because they required both a control signal and control power. This resulted in a more expensive part as well as additional support cost for wiring, conduit, and labor. For these reasons, it was determined that utilizing a simple 120V solenoid valve would suffice to control blowdown. Additionally, this valve was selected to fail shut such that a loss of power would not result in an uncontrolled blowdown.

System response and stability required additional modifications to ensure optimal operating efficiency. Blowdown Piping consisted of ¾" PVC piping, which supported both the blowdown and sample panel. During blowdowns, discharged water would at times starve the panel resulting in a low flow condition. In order to improve and prevent this, the ¾" PVC was replaced with 1" PVC to reduce pressure drop. This increased pipe schedule also served to increase blowdown rate, allowing for quicker system response to TDS.

In order to maintain operability in case of a failure in the automation controls or components, a bypass valve was added to the solenoid valve. A PVC globe valve was used to give the operator throttling capabilities in case the system failed. Additionally, when left partially open, this valve can enable a controlled continuous blowdown. This continuous blowdown reduces the rate at which TDS builds up both reducing overshoot and solenoid valve cycling.

Additionally, for cost saving purposes, many measures were taken to reuse existing utilities. The location of the solenoid was chosen to correspond to an existing electrical conduit that was no longer in service to remove the need for installing new conduit. A terminal junction box was installed adjacent to CL-49 pump to allow use of factory wiring that would not reach the panel. The junction box was also prewired to allow additional 4-20mA hook ups should expansion be desired in the future.

2.3 MECHANICAL IMPLEMENTATION

An initial design was generated and discussed with operations, maintenance and engineering departments to ensure buy-in and funding. The system drawings were then updated to reflect the desired piping and electrical changes. These drawings went

through an engineering review process to ensure code compliance, safety and general engineering approval.

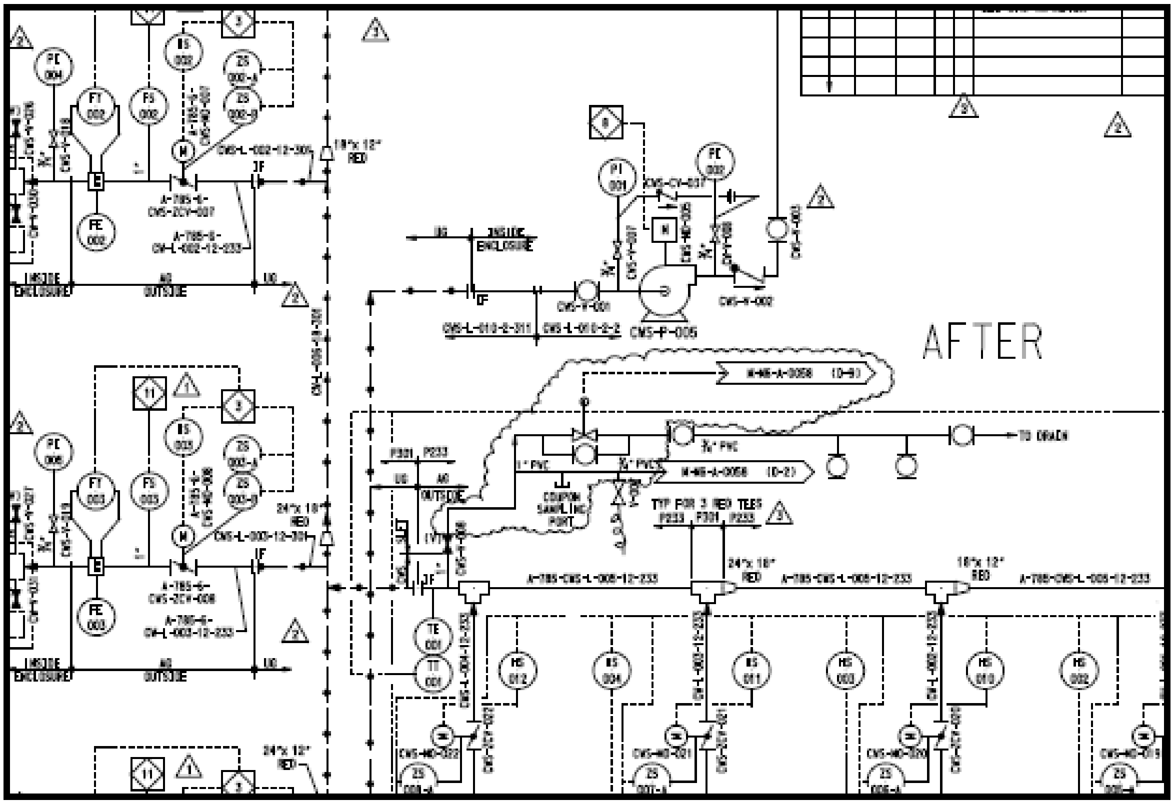

Figure 2.1. Mechanical drawing showing the required piping change

Once the drawings were approved, a work package was generated. This work package included a parts list and work instructions. This work package was simple in nature, yet complex in implementation, requiring approval from industrial hygiene, operations, maintenance, engineering, safety, and management. The process of getting the work approved included several walk downs to receive buy-in and approval. After approval, the parts were ordered and the work was scheduled.

Part	Quantity	Requirement
CAT cable	~30ft	Shielded Twisted (CAT 6 STP or 6a STP)
8-Pin Cable	1-3feet	OEM (Provided)
4-20mA card	1-4	OEM (Provided)
Terminal Junction box	1	Min 8 terminal
1” Globe OR V-Notch Ball Valve	1	Operator accessible
1” solenoid Operated valve	1	120v normally shut, NEMA 3
1” PVC	~20 feet	Schedule 40
PVC Fittings	Assorted	Solvent weld
3 wire Cable	~100 Feet	14 Gauge

Figure 2.2. Parts list, cost $1,100

After the job was scheduled, work began. Mechanical work was completed first, with piping changes and valve installations being completed without incident. Electrical work was completed; power routed, communication lines connected, terminal block installed, and 4-20mA cards installed.

Start	Cable	Color	Terminal	Cable	Color	End
4-20mA Card 1 + (Pos)	CAT	Blue	1	8-Pin	Violet	Pin 3
4-20mA Card 1 + (Neg)	CAT	Blue/White	2	8-Pin	Green	Pin 4
4-20mA Card 2 + (Pos)	CAT	Orange	3	N/A	N/A	N/A
4-20mA Card 2 + (Neg)	CAT	Orange/White	4	N/A	N/A	N/A
4-20mA Card 3 + (Pos)	CAT	Brown	5	N/A	N/A	N/A
4-20mA Card 3 + (Neg)	CAT	Brown/White	6	N/A	N/A	N/A
4-20mA Card 4 + (Pos)	CAT	Green	7	N/A	N/A	N/A
4-20mA Card 4 + (Neg)	CAT	Green/White	8	N/A	N/A	N/A

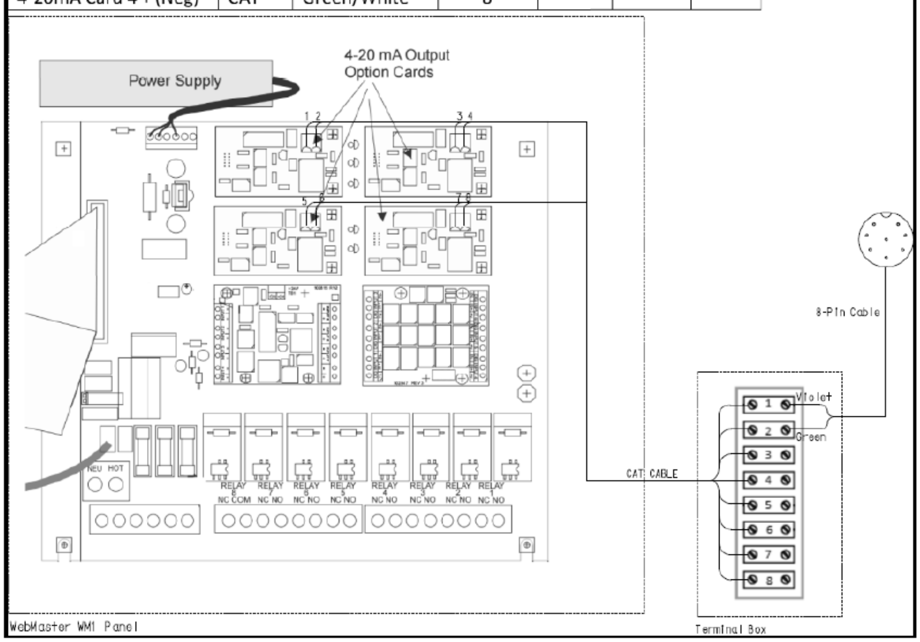

Figure 2.3. Electrical 4-20mA wiring diagram

2.4 SOFTWARE SET UP

Panel board has GUI that was accessed via laptop connected through USB. After drivers were installed GUI for panel was accessed and Blowdown set points were set. Initially a blowdown was set to begin at 200uS and stop at 190uSm. This low set point was chosen to ensure control capabilities under extreme load. After control was shown between 190-200 Ms, the range was raised to 360-370uS to achieve the project goal of 4.5 cycles of concentration.

The panel board's GUI was also used to enable 4-20mA output based on Cl ppm. With a desired range of 0.5-1.0 ppm, the 4-20mA set points were bounded such that at 0.5 ppm, a 4mA signal was transmitted and at 1 ppm a 20 mA signal was transmitted. The pump was then configured to run in automatic instead of manual mode. The pump was set to 20 pumps/min at 20 mA and 75 pumps/min at 4 mA. These pump speeds are based on the highest and lowest recorded pump speeds used during manual operation. After two weeks, the panel range was increased to 0.3-1.2. This lowered the average Cl and resulted in reduced overshoot during operation.

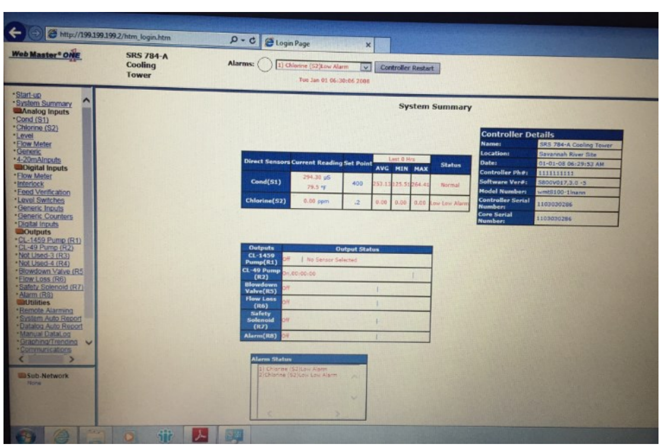

Figure 2.4. GUI for Webmaster Panel Board

CHAPTER 3: METHODOLOGY

3.1 GENERAL

The site in which this automated chemistry control system was implemented is required to pay for utility usage, but does not track specific distribution of use across the site. As such, there is no water meter that measures the number of gallons added to the cooling tower, so there is no direct method of measuring improvements. To this end, it becomes important to model system parameters to create an accurate prediction of current water usage, future usage, and potential operating advantages.

There are 4 primary variables in the equation regarding water usage, evaporation, water added, and resulting TDS. Due to the unknown amount of water added, it is necessary to extrapolate that information. The resulting TDS is readily available as it is logged daily. Evaporation is a complex issue dependent on weather and customer usage. Once evaporation is determined, it becomes possible to estimate the water used based on the resulting TDS (4).

3.2 MODELING MANUAL CONTROL

Prior to implementation of the automated chemistry control system, both TDS and Cl were controlled manually through once-a-day inspection. Prior to implementation of the automated chemistry control system, both TDS and Cl were controlled manually with large operating bands and non-specific instructions. Previously, operators were expected to control both TDS and Cl based on “skill of trade.” This resulted in variation between

operators. While some operators attempted to manually operate in a tight band through daily adjustments, other operators only adjusted blowdown and pump rates when readings approached system limits, which resulted in occasional overshoot. In either case, due to imprecise tools, unpredictable weather, user created demand, and the ability to only adjust settings once per day, manual control was erratic.

In order to model manual control, a years' worth of logs were pulled and compiled for analysis. As seen when evaluating figure 1.6, it is clear there are erratic and varied results associated with manual control. The manual control data was compiled into a histogram shown in Figure 3.1, and was compared against Weibull, Normal, and Gamma distributions. This data most closely followed a normal distribution with a mean of 279 and a standard deviation of 60.68. This same process was completed for free Chlorine and resulted in a mean of 0.691 and a standard deviation of 0.329, as shown graphically in figure 3.3.

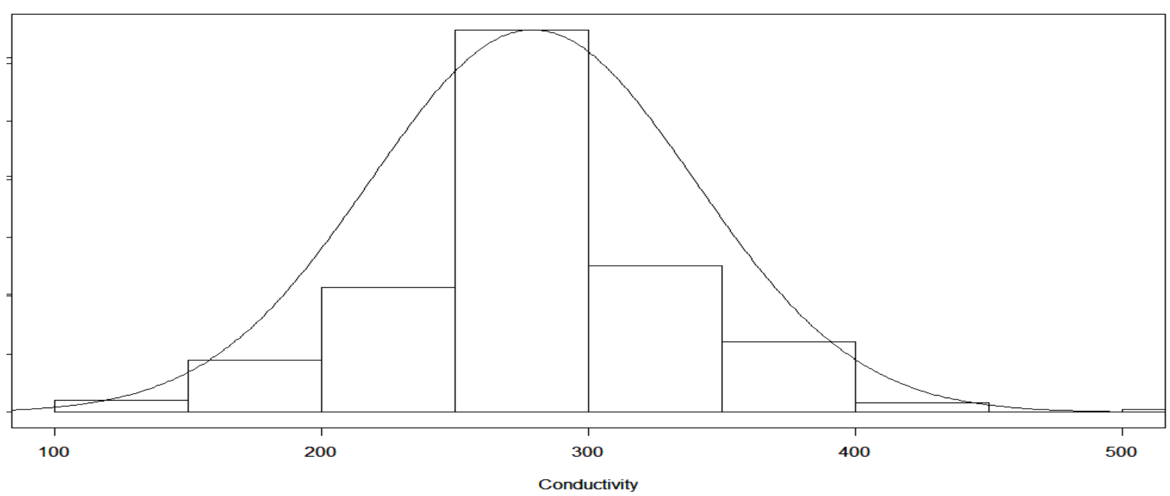

Figure 3.1. Manual control modeling, histogram of 1 years' worth of Conductivity logs with the representative normal distribution overlaid.

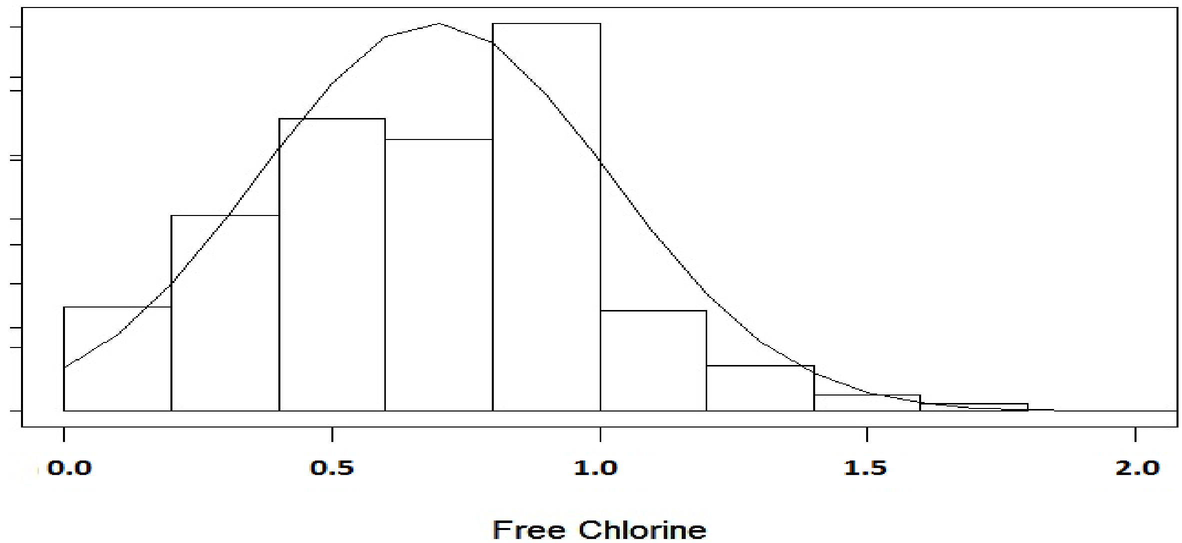

Figure 3.2. Manual control modeling, histogram of 1 years' worth of Cl logs with the representative normal distribution overlaid.

3.3 MODELING AUTOMATIC CONTROL

Following implementation of the chemical control system, the system response became extremely consistent. In order to model system response under automatic control, a much smaller sample period was necessary. This is due to the consistent response, controller logging, and intentional testing.

Following implementation of the automatic control system, the system responds consistently and unless an outside parameter is affected, the effects on the system are identical to previous system responses. In addition, now that the controller is being used, data logging has enabled an increase in the frequency of sample collection from daily to hourly. This increase in samples allows for a more accurate representation of each day and enables more thorough system analysis.

Following implementation of the chemical control system, testing has been performed on the system to determine capabilities. Due to the exponential increase in water demand in relation to decreasing TDS, determining the range of control is

necessary. A continuous blowdown has been initiated from a TDS of 327, and this blowdown continues until readings level off at around 180u. This represents the lowest TDS that the system can operate under given the current conditions.

The system has also been tested at varying operating bands to compare the system response. TDS bands of 190-200, and 360-370 have been compared. In each case, the system can maintain control with minimal overshoot. Data analysis revealed a uniform distribution. This difference in distribution is credited to the small operating band which results in an effectively linear change in TDS in regards to time.

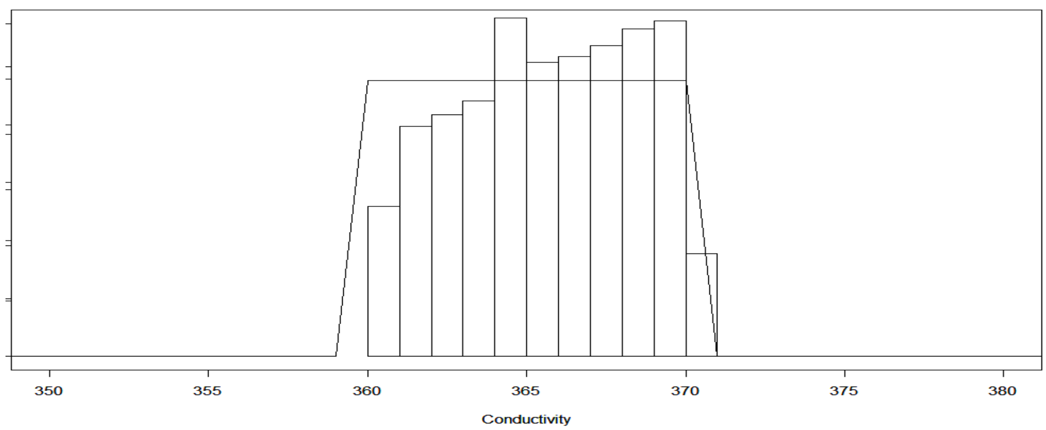

Figure 3.3. Histogram of for conductivity with the representative normal distribution overplayed.

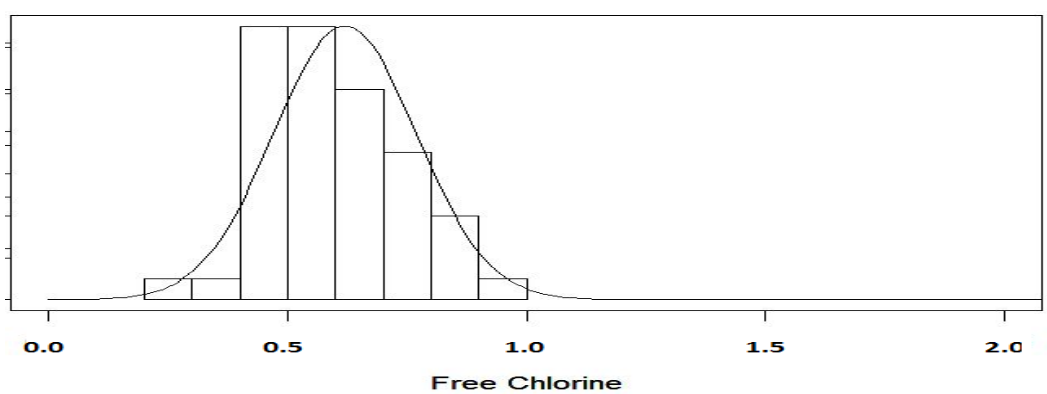

Figure 3.4. Histogram of for Free Chlorine with the representative normal distribution overlaid

3.4 SIMPLIFYING EVAPORATION

The Rate of Evaporation is dependent on many variables including temperature, wind, and flow rate. Accurately modeling these variables and their effect on the rate of concentration would be difficult, even with many available data points. However, the data for local temperature, wind velocity, and speed are not available, making modeling for the rate of evaporation based on these factors impossible. As it is, the flow rate is dependent on demand, with additional pumps and towers brought online as demand increases. By industry practice, thumb rules exist to approximate rate of evaporation based on recirculation rate, cooling range, and evaporation factor.

This Evaporation rate is independent of changes made to the system through the automation process, and is based on uncontrollable factors. As such, a single average evaporation rate was found based on a years' worth of readings. This average evaporation rate was used as a baseline for comparing the average blowdown rate both before and after the modification.

$$E = \frac{RR(\Delta T)F}{1000} \qquad \text{Equation 1. (1)}$$

Equation 1 was used to determine an average 'E' for the given year. F, the evaporation factor, typically ranges from 0.75-1.0 where 1.0 is the typical default assumption (1). Based on our Chemtreat's area consultant, a value of 0.9 was chosen as a conservative number. This yielded a value of 97.2 for 'E'.

3.5 BLOWDOWN DETERMINATION

Water lost through blowdowns is replaced due to level control. By reducing the amount of water blown down, the total amount of water supplied is reduced by an equal

amount. In order to determine the average blowdown, the distribution models for before automation and after automation were used to represent concentration of blowdown. 80uS is the expected concentration of makeup water supplied and was used in addition to the average evaporation rate found previously.

Cycles = $\dfrac{Concentration\ of\ blowdown}{Concentration\ of\ makeup}$ Equation 2. (1)

BD = $\dfrac{E}{(cycles-1)}$ Equation 3. (1)

For each of the models of conductivity, 10,000 data points were randomly generated based on the distribution. These data points represent the probability of a given conductivity at a point in time. These 10,000 data points were then substituted for "Concentration of blowdowns" in equation 2, and 80uS was utilized for "concentration of makeup". The resulting 10,000 cycles were then used in equation 3 in combination with the 'E' determined from equation 1 to find 10,000 blowdown rates. The average of these blowdown rates was then taken, resulting in an average blowdown of 44.65 Gal/min for the automated system and 27.2422 gal/min for the manual system. This is a reduction of 17.41 Gal/min or 9,153,650 gallons of water per year.

3.6 Cl DETERMINATION

As a result of the water chemistry of the well water used for service water, the Chlorine demand of service water is effectively zero. As a result, free Cl that is monitored acts in direct proportion to the CL-49 added to the system. Further, due to the limited consumption of Cl, replenishment of exhausted Cl can be removed from the equation. As a result of these factors, Cl requirements are directly tied to the volume of

make-up water. Due to the automation the amount of CL-49 utilized has changed due to two primary factors.

First, due to the reduced blowdown, less water is added to replenish this lost water. This reduces the amount of water needing CL-49 treatment. From utilizing the blowdown rates and evaporation rates determined previously, we know that the before and after expected makeup rates are 142.85 Gal/min and 124.44 Gal/min. On an annual basis, this results in makeup rates of 74,556,360 Gal/year and 65,406,820.32 Gal/year.

MU = $E + BD$ Equation 4. (1)

The second factor that has an effect on the amount of CL-49 used is the automated control of CL-49. In order to determine the net effect of the automation process, the model for Cl under manual control was applied to the initial makeup rate to determine an initial CL-49 model. The model of Cl under automatic control was applied to the final makeup rate to determine the resulting CL-49 demand. Due to the linear relationship between CL-49 and free chlorine, the percent difference found correlates to the percent difference in usage (1). This resulted in 21.2% reduction in CL-49 usage.

CHAPTER 4: RESULTS OF IMPLIMENTATION

4.1 IMPROVEMENT IN OPERATIONAL CONTROL

One of the most significant improvements resulting from automating the cooling tower is not able to be measured financially. Both Cl and TDS control have significantly improved and been simplified. As seen in Figures 4.1 and 4.2, both operating bands have been significantly tightened and shifted. Shifting these new operating bands now takes as little as 5 minutes, allowing for effective chemistry control.

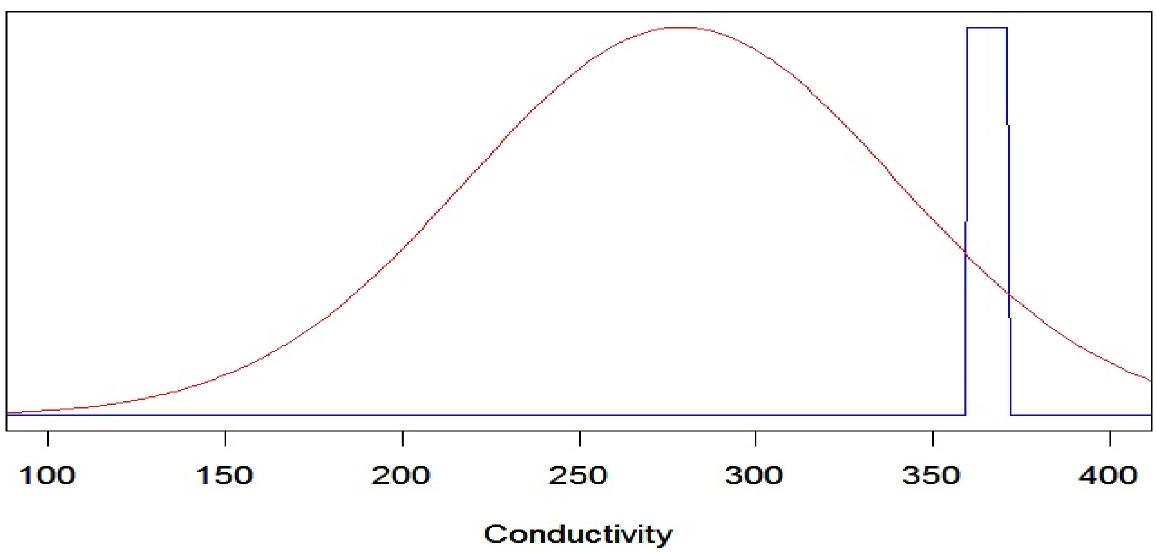

Figure 4.1. The before and after probabilities of conductivity in red and blue, respectively

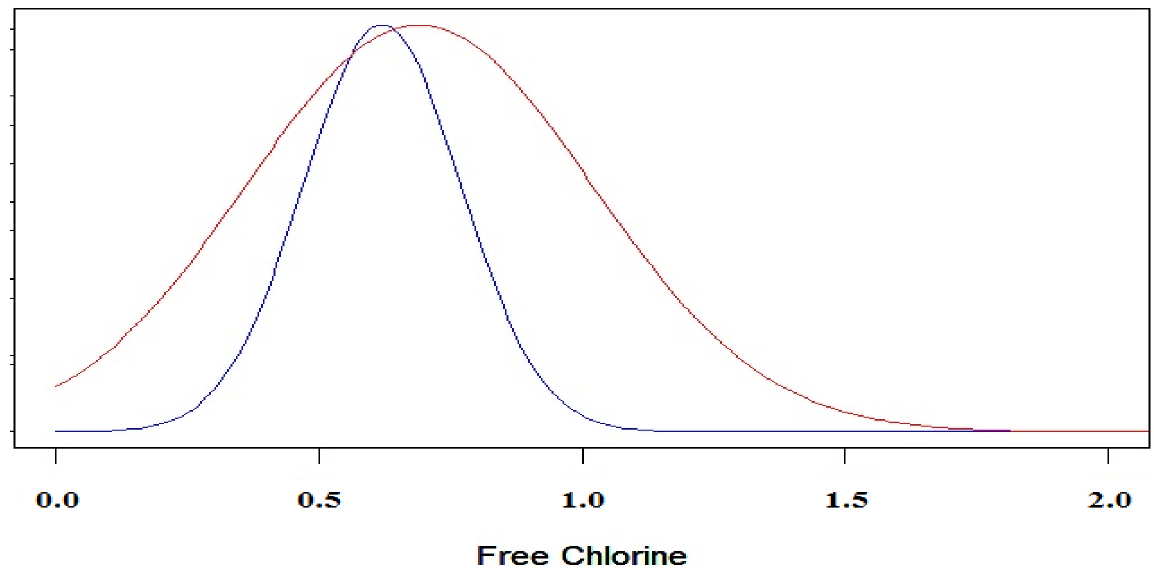

Figure 4.2. The before and after probabilities of free Chlorine in red and blue, respectively

4.2 REDUCTION IN WATER USAGE

The majority of makeup water required for the system is a result of evaporation which is not a controllable factor. The total expected usage was reduced from 74.6 million gallons per year to 65.4 Million gallons per year. This 9.1 million gallon savings is extrapolated, but represents a 12.2% reduction in demand. The site operates its own wells and treats its own service water; as a result, the cost per gallon is significantly lower than the industry standard (5). The site water cost is approximated at $0.5/1000gal a fraction of the standard industry cost (3). This yields an estimated potential savings of $4575 per year.

4.3 REDUCTION IN CL-49 USAGE

The site's annual use of CL-49 varies and the average use over the past 3 years is in excess of $15,000 per year (3). With a 21.2% reduction in CL-49, at least $3180 of savings per year is anticipated.

4.4 REDUCTION IN MAN HOURS

Currently, the site devotes approximately 10 man hours per week to servicing the cooling tower (3). A majority of these hours is a result of travel time which will not be effected until the frequency of servicing is reduced. Previously, operators estimated that 2 hours per week was spent adjusting Cl and conductivity rates, this time will no longer be needed. Currently, operators are paid in excess of $50 per hour, so automation resulted in projected cost savings of $260 per year (3).

4.5 TOTAL COST SAVINGS

Total realized cost savings is projected to be $8,015 per year. The cost of materials and labor was kept bellow $2,000 (3). As a result, the initial investment should be returned inside of 3 months.

CHAPTER 5: PATH FORWARD

5.1 EXPAND OPERATING BAND

By industry practice, TDS is limited to prevent system saturation resulting in precipitation (2). This TDS precipitation limit is based on water chemistry and varies based on water supply. Typical ranges of TDS precipitation limits exceed 700uS, however due to biological concerns the site has placed a 400uS limit to aid in chemistry control (2).

As chemistry control is improved, it is expected that biological growth will be reduced due to deliberate and controlled operation. The 400uS limit may be raised in the future, further increasing the cycles of concentration and reducing water and CL-49 demand.

5.2 REDUCE OPERATOR ROUND FREQUENCY

Operators continue to round daily due to the previous need to make frequent changes to blowdown rates and CL-49 addition. Due to automation control, this need no longer exists, and after a 1year proof of reliability, frequency of rounding will likely decrease.

Further, the panel has the capability for expansion to include cellular and network communications. If remote communication functionality is added, operator rounds could potentially be eliminated. With remote communications, alerts would be sent if specs go

out of range or if the system experiences a failure. This could reduce operator rounds significantly.

5.3 PH AND PRECIPITANT CONTROL

Testing the addition of an acid and metal precipitation to improve biological growth control is currently in planning, and is expected to begin in October 2016. If either or both options prove beneficial to biological growth control, permanent methods of control would be available through the panel boards.

To control pH, acid would be injected into the basin in a similar method that CL-49 is currently added. To monitor, a pH meter would need to be added to the panel board piping. This pH meter is currently available through the vendor. To precipitate is not readily measurable, and would be metered in at a given rate during blowdowns.

5.4 ADDITIONAL COOLING TOWERS

The site operates a total of five cooling towers, of which two are controlled through other means, two are controlled manually, and this tower is now automatic. The two towers that are controlled through other means use solid Cl addition that is mechanically controlled. These towers would receive minimal benefits from additional automation. The two towers that are manually controlled are not as problematic as the modified tower, yet their benefits would still exist.

BIBLIOGRAPHY

1. *Betz Handbook of Industrial Water Conditioning.* Trevose, PA : Betz Laboratories, 1971.

2. Best Management Practice #10: Cooling Tower Management. *Energy.gov.* [Online] [Cited: February 02, 2016.] http://energy.gov/eere/femp/best-management-practice-10-cooling-tower-management.

3. Document, DOE Contract. Due to ongoing DOE contracts and security reasons specific values have been approximated.

4. *50 Largest Cities Water/Wastewater Rate Survey.* s.l. : Black & Veatch, 2013.

5. McDonald, James. Cooling Tower Blowdown Equation. *veoliawatertech.* [Online] July 2003. [Cited: January 3, 2016.] http://www.veoliawatertech.com/crownsolutions/ressources/documents/2/21963,Water-pp417-418.pdf.

APPENDIX A– ADDITIONAL PHOTOS

Figure A.1 Cooling towers

Figure A.2 Chemical Tanks; Left CL-49 & Right CL-1459 (not in use)

Figure A.3 Cooling towers Level Control Float

Figure A.4 System Pumping Platform

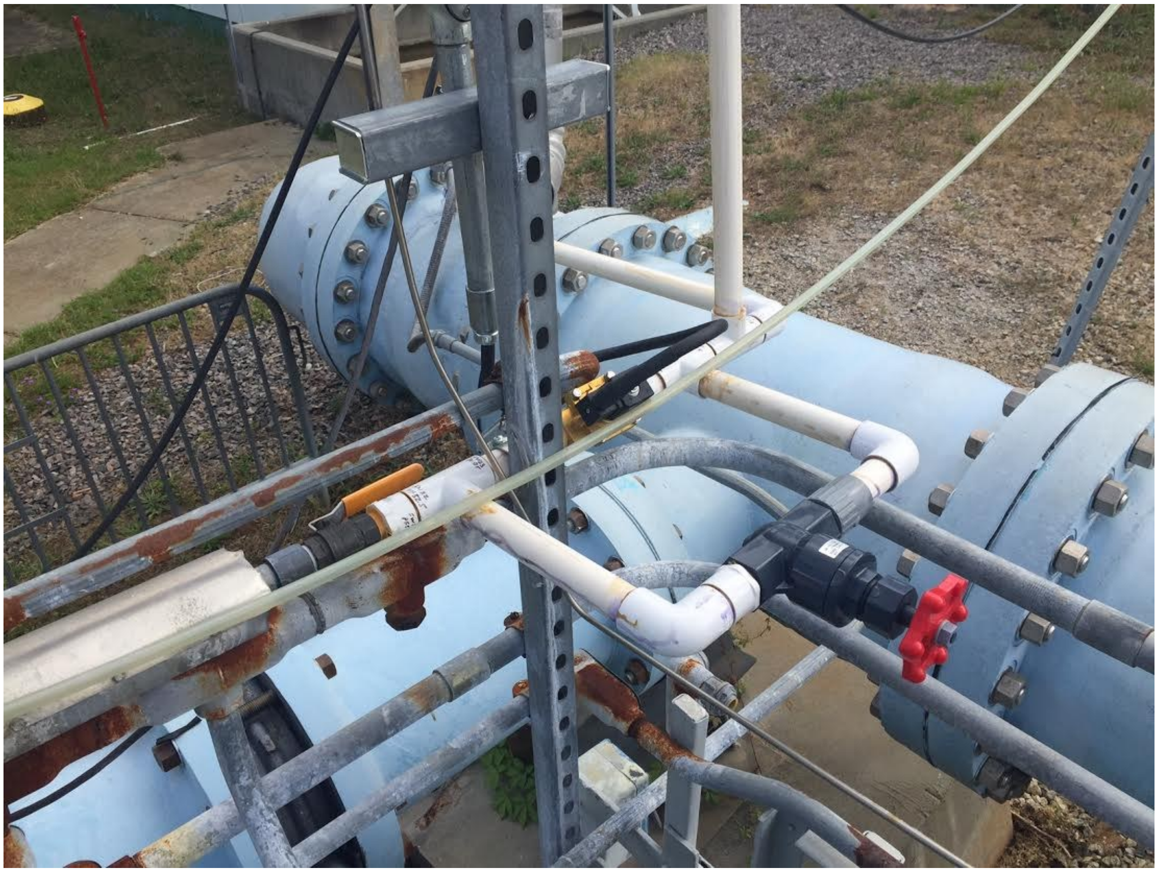

Figure A.5 New solenoid valve with bypass

APPENDIX B– R STAT CODE

#File retrieval#

```
getwd()
setwd("R")
data<-read.csv(file="data.csv", head=TRUE, sep=",")
summary(data)
a<-hist(data$Cond)
b<-hist(data$Cl)
h <- seq(0,1600)
f <- dnorm(h,275,60.77)
```

#Conductivity Test for Normal Distribution#

```
ll <- function(mu, sigma){
  pdfw <- dnorm(data$Cond,mu,sigma)
  -sum(log(pdfw))
}
library(stats4)
mle(ll,start=list(mu=279.7,sigma=60.68),
method='L-BFGS-B',lower=c(0,0))
x <- sort(data$Cond)
n <- length(x)
S <- seq(1,n)/n
F <- pnorm(x,279,60.68)
D <- max(abs(F-S))
```

```
D
```

 # Conductivity Test for Weibul Distribution#

```
ll <- function(mu, sigma){
  pdfw <- dweibull(data$Cond,mu,sigma)
  -sum(log(pdfw))
}
library(stats4)
mle(ll,start=list(mu=4.36,sigma=303.7),
method='L-BFGS-B',lower=c(0,0))
x <- sort(data$Cond)
n <- length(x)
S <- seq(1,n)/n
F <- pweibull(x,4.36,303.7)
D <- max(abs(F-S))
D
```

 # Conductivity Test for gamma Distribution#

```
ll <- function(mu, sigma){
  pdfw <- dgamma(data$Cond,mu,sigma)
  -sum(log(pdfw))
}
library(stats4)
mle(ll,start=list(mu=21.4,sigma=.0765),
method='L-BFGS-B',lower=c(0,0))
x <- sort(data$Cond)
```

```
n <- length(x)
S <- seq(1,n)/n
F <- pgamma(x,21.4,.0765)
D <- max(abs(F-S))
D
```

 # Plot data Histogram vs normal/gamma/Weibul #

```
h <- seq(0,1600)
f <- dweibull(h,4.36,303.7)
plot(h,f,type='l', xlab="Conductivity", xlim=c(100, 500))
par(new=TRUE)
i <- seq(0,1600)
j <- dnorm(i,279,60.68)
plot(i,j,type='l', xlab="Conductivity", xlim=c(100, 500))
par(new=TRUE)
k <- seq(0,1600)
m <- dgamma(k,21.4,.0765)
plot(k,m,type='l', xlab="Conductivity", xlim=c(100, 500))
par(new=TRUE)
plot(a, xlab="Conductivity", xlim=c(100, 500))
```

 # Cl Test for Normal Distribution#

```
sd(data$Cl)
ll <- function(mu, sigma){
  pdfw <- dnorm(data$Cl,mu,sigma)
  -sum(log(pdfw))}
library(stats4)
```

```
mle(ll,start=list(mu=.69067,sigma=.3295),
method='L-BFGS-B',lower=c(0,0))
x <- sort(data$Cl)
n <- length(x)
S <- seq(1,n)/n
F <- pnorm(x,.690674,.32954)
D <- max(abs(F-S))
D
# Cl Test for Gamma Distribution#
ll <- function(mu, sigma){
  pdfw <- dweibull(data$Cl,mu,sigma)
  -sum(log(pdfw))
}
library(stats4)
mle(ll,start=list(mu=2.1635,sigma=.7757),
method='L-BFGS-B',lower=c(0,0))
x <- sort(data$Cl)
n <- length(x)
S <- seq(1,n)/n
F <- pweibull(x,2.1635,.7756)
D <- max(abs(F-S))
D
# Cl Test for Weibul Distribution#
ll <- function(mu, sigma){
  pdfw <- dgamma(data$Cl,mu,sigma)
```

```
  -sum(log(pdfw))
}
library(stats4)
mle(ll,start=list(mu=3.065,sigma=4.438),
method='L-BFGS-B',lower=c(0,0))
x <- sort(data$Cl)
n <- length(x)
S <- seq(1,n)/n
F <- pgamma(x,3.065,4.437)
D <- max(abs(F-S))
D
```

 # Plot Cl Histogram vs normal/gamma/Weibul #

```
h <- seq(0,1600)
f <- dweibull(h,2.1635,.7756)
plot(h,f,type='l', xlab="Cl", xlim=c(0, 2))
par(new=TRUE)
i <- seq(0,1600)
j <- dnorm(i,.69067,.32954)
plot(i,j,type='l', xlab="Cl", xlim=c(0, 2))


par(new=TRUE)
k <- seq(0,1600)
m <- dgamma(k,3.065,4.437)
plot(k,m,type='l', xlab="Cl", xlim=c(0, 2))
par(new=TRUE)
```

```
plot(b, xlab="Cl", xlim=c(0, 2))

par(new=TRUE)

g<-rnorm(100, .69, .329)

hist(g, xlab="Cl", xlim=c(0, 2))
```