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Demonstration of Electronic Capacitor-Based Water Treatment System for Application at Military Installations

Alfred D. Beitelman, M. Michael Pitts Jr. PhD,
Rodrigo F. V. Romo, and Carolyn B. Pitts

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Alfred D. Beitelman

Construction Engineering Research Laboratory
U.S. Army Engineer Research and Development Center
2902 Newmark Drive
Champaign, IL 61822
Phone 217-373-7237

Dr. M. Michael Pitts Jr., Rodrigo F. V. Romo, and Carolyn B. Pitts

Zeta Corporation
2045 N. Forbes Boulevard
Suite 102
Tucson, Arizona 85745
Phone 520-903-9904

Final report

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Abstract: The United States Department of Defense (DoD) has a specific legislative mandate to increase its conservation of water and energy. It also is interested in improving the effectiveness of open-loop, cooling water treatment processes at its installations worldwide, for purposes of extending the useful life of evaporative cooling equipment and reducing energy use/costs. A Cooperative Research and Development Agreement (CRADA) was approved to demonstrate that, without using chemical additives, a capacitor-based water treatment system is capable of (1) providing equivalent protection to a chemical treatment program in preventing scale, corrosion, and bio-fouling; (2) allowing cooling systems to be operated in an enhanced water conservation mode; (3) delivering measurable reductions in water usage over conventional methods; and (4) providing control, monitoring, and wireless data transfer via the Internet. Results documented in the subsequent demonstration and evaluation project showed the technology was able to meet every objective and also was able to deliver a 20% reduction in cooling water use over standard chemical treatment methods. Application of this technology would allow the DoD to (1) reduce chemical usage, exposure, and disposal expenses; (2) conserve water and energy; (3) facilitate water re-use; and (4) meet new goals for conservation of resources.

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Preface

This study was conducted as a Cooperative Research and Development Agreement (CRADA) between U.S. Army Engineer Research and Development Center – Construction Engineering Research Laboratory (ERDC-CERL), AquaLucid Consultants, Inc. and Zeta Corporation. The specific project is known as CRADA -07-CERL-04: "Demonstration/Evaluation of Zeta Rod Systems for the Treatment of Evaporative Cooling Equipment on U.S. Military Bases," dated March 2007.

The work was performed by the Materials and Structures Branch (CF-M) of the Facilities Division (CF) at ERDC-CERL. At the time of publication, Vicki Van Blaricum was Chief, CEERD-CF-M and Michael Golish was Chief, CEERD-CF.

The authors also wish to acknowledge the cooperation and efforts of other personnel, including all military personnel who assisted. Specifically, Solomon Williams of Tyndall AFB provided guidance in developing and monitoring the program. In addition, Oscar Rueda of Davis Monthan AFB, and Bill Stein and Sam Montanez of Fort Huachuca provided excellent base coordination.

The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti and the Director was Dr. Ilker Adiguzel.

COL Gary E. Johnston was the Commander and Executive Director of ERDC, and Dr. James R. Houston was the Director.

Unit Conversion Factors

Quantity	Equals
gallons (U.S. liquid)	3.7854 L
1 gal (U.S.)/min	0.063 L/sec
1 mil	0.0000245 m
Ton of Refrigeration	3.517 kW
°F	(C x 1.8) + 32
1 ccf	748 gal.

1 Introduction

1.1 Background

The United States Department of Defense (DoD) has identified a need to improve the effectiveness of its water treatment protocols for the purpose of extending the useful life of the many types of evaporative cooling equipment found at military installations worldwide. The primary objective is to seek ways to reduce capital and maintenance expenditures and to increase equipment efficiency by keeping heat transfer surfaces clean. In addition, by adopting a “green” technology or methodology, the military might be able to reduce chemical usage, exposure and disposal expense; conserve water and energy; facilitate water re-use; and meet new DoD goals for conservation of resources in response to Executive Order 13423[1] signed by President Bush on January 24, 2007, which directs (in part) under Section 2, *Goals for Agencies*:

> ...(c) beginning in FY 2008, reduce water consumption intensity, relative to the baseline of the agency's water consumption in fiscal year 2007, through life-cycle cost-effective measures by 2 percent annually through the end of fiscal year 2015 or 16 percent by the end of fiscal year 2015;...(e) ensure that the agency (i) reduces the quantity of toxic and hazardous chemicals and materials acquired, used, or disposed of by the agency, (ii) increases diversion of solid waste as appropriate , and (iii) maintains cost-effective waste prevention and recycling programs in its facilities;...

Evaporative cooling systems, such as cooling towers and evaporative condensers, represent the two most common ways of removing heat from industrial and commercial process equipment. In all cases, the practice of evaporating water to cool spaces or to provide cooling for industrial processes produces concentrations of the mineral salts inherent to water supply sources. In addition, nutrients from airborne sources and make-up

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[1] Federal Register Vol. 72, No. 17, Friday, January 26, 2007, Part II, The President, Executive Order 13423 – Strengthening Federal Environmental, Energy, and Transportation Management. Title 3- Executive Order 13423 of January 24, 2007.

water contribute to accumulations of micro-organisms in the recirculating cooling water and allow for increases in water-borne populations of bacteria, which may include disease-causing microorganisms such as *legionella pneumophila*. Water-cooled equipment that accumulates deposits from mineral or biological origin is subject to loss of heat-transfer efficiency and to rapid degradation by corrosion.

Historically, control and prevention of these destructive, expensive and potentially hazardous conditions has been accomplished by adding specialty chemicals to the cooling water. These chemicals are often hazardous and require special storage and handling. Their proper application consumes man-hours and is subject to error through a number of water quality variations that complicate the task of managing a chemical program for good results.

Availability of an effective, non-chemical method of water treatment would open the possibility of reusing water for irrigation or other types of gray water uses, and would reduce exposure of hazardous chemicals to humans and the environment. Evaporative cooling equipment that remains consistently free of deposits under a technically advanced water treatment program would hold energy consumption in cooling equipment to original design levels and would prevent the increased energy consumption that accompanies even slight levels of scale formation and bio-fouling.

One such technology that is well established in the private sector, but has yet to be widely adopted by the U.S. Government, is a patented, electronic capacitor-based device used to prevent deposits, corrosion and bio-fouling in aqueous systems. Zeta Corporation, a U.S. corporation, is the developer, patents holder, and manufacturer of technology sold under the trade name Zeta Rod.[2] The modular system is easily adapted for installation into new, or existing, evaporative cooling systems of various sizes and configurations.

1.2 Objectives

There were three objectives to this demonstration/validation project: (1) to demonstrate that without using chemical additives, the Zeta Rod system

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[2] Zeta Rod® is a registered Trademark of Zeta Corporation, headquartered in Tucson, Arizona. Zeta Rod systems are protected by U.S. Patent No. 5,591,317. Other U.S. and international trademarks and process patents have been granted or are pending.

would produce an equivalent level of performance and protection for evaporative cooling equipment, compared to that produced through a conventional chemical water treatment program, with respect to scale prevention, biofouling, and corrosion control; (2) to demonstrate that the technology could deliver additional efficiencies in water conservation and waste water reduction; and (3) to develop and demonstrate a remote monitoring and control system operable via an interface that is wireless, and Web-accessible.

1.3 Approach

To assess the potential for use of the non-chemical and wireless monitoring technology in evaporative cooling equipment on military installations, the U.S. Army Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) entered into a Cooperative Research and Development Agreement (CRADA) with AquaLucid Consultants, Inc. and Zeta Corporation for a 16-month, side-by-side, comparative study of the technology against a standard chemical treatment program that was performing at its expected level of efficiency. The demonstration/validation (DEM/VAL) project began May 2007 at Davis Monthan Air Force Base (AFB) near Tucson, Arizona, and Fort Huachuca Army Garrison in southeast Arizona.

2 Evaporative Cooling System Designs

Evaporative cooling systems which pair a cooling tower with a water-cooled chiller or water-cooled condenser are the most common designs for removing heat from industrial production areas and for large air-conditioning and refrigeration (HVACR) applications.

Heat is removed from the water via water-to-air transfer and evaporation, and the warm air and water vapor pass into the atmosphere. In HVACR applications, the cooling tower removes heat from the refrigerant in the condenser as part of the refrigerant thermal cycle. The heat removal process is the same in all refrigeration designs, but the equipment used is different in design so as to accommodate heat load and economic considerations. Figure 1 illustrates a typical configuration of a cooling tower-chiller system used in an air conditioning application for a building.

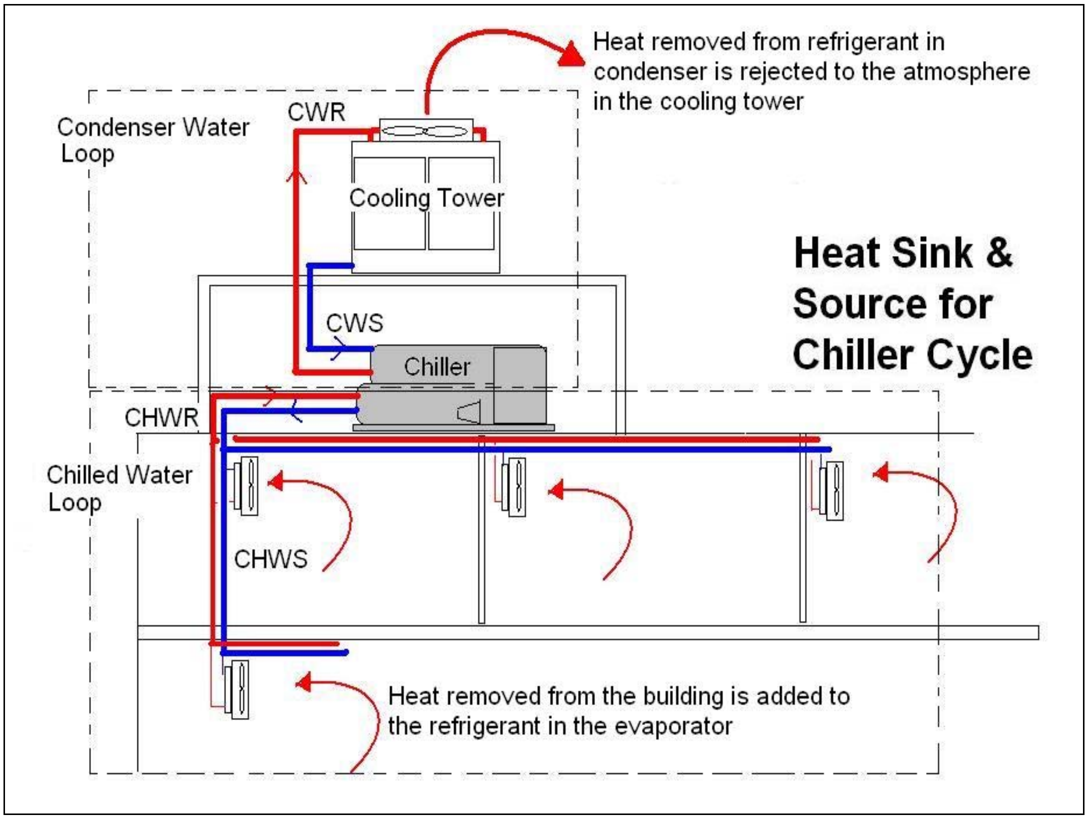

Figure 1: Typical configuration of equipment used in an HVACR process.

An Evaporative Condenser design (Figure 2) differs by having water flowing in open air over the exterior of tubes containing hot refrigerant. The tube–bundle is inside a tower structure. Water is sprayed over the exterior of the tubes, and cascades down to a catch-basin from which it is immediately circulated back to the spray nozzles. Rising warm air and water vapor carry the heat into the atmosphere. Evaporating water on the outside of tubes, without effective water treatment, imposes a more demanding challenge for the control of fouling.

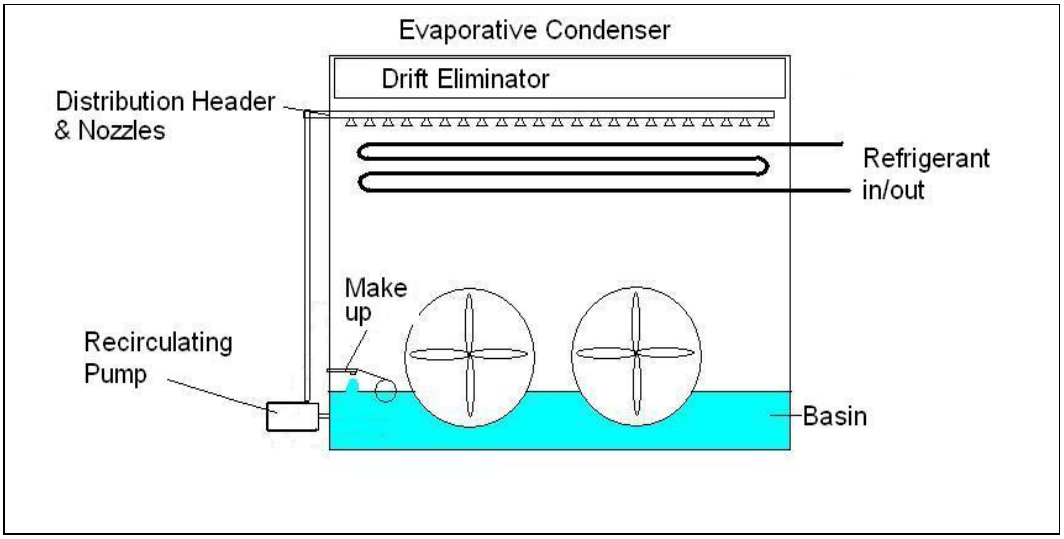

Figure 2: Evaporative condenser system.

The main challenge in maintaining efficient operation of evaporative cooling systems is related to water treatment.

3 Cooling Water Treatment

3.1 Expectations and definitions

Any discussion of cooling water treatment must begin with an objective statement of what is expected from the evaporative cooling equipment. Critical cooling needs for industrial processes or protection of sensitive equipment may require a more disciplined approach than one used for other, less critical, cooling functions. A complete cooling water treatment program should meet all four of the following objectives, and be done in a cost-effective and environmentally acceptable manner that protects human health and safety (Blake 1980; Freije 1996; McCoy 1983).

1. Water conservation
2. Scale control
3. Biofouling control
4. Corrosion protection

There are three competing circumstances present when operating evaporative cooling systems. First, the water conservation effort requires high re-use of the water before discharge to the waste drain. Second, the mineral salts and suspended air particles that pass through the tower remain after the water evaporates and become concentrated. (The concentrated minerals and the particles from the atmosphere can build deposits that interfere with efficient heat transfer and cause corrosion.) Third, the conditions in an evaporative cooling system—warm water temperature and high aeration rates—create the ideal environment for bacteria and microorganisms to thrive, creating a potential scenario for microbially induced corrosion (MIC), heat transfer losses due to biofilm deposits, and potential health hazards due to pathogenic bacteria growing within biofilm deposits.

The following terms are used throughout this paper. Brief definitions are given here:

- **Scale:** Mineral deposits that form on wet surfaces in an evaporative cooling system as a result of minerals in the water exceeding their solubility levels, precipitating out of the water, and forming a deposit.
- **Biofilm:** A deposit of an organic nature that forms on the wet surfaces of an evaporative cooling system. Biofilms are a complex matrix con-

sisting primarily of an exo-polysaccharide (EPS) sugar-based compound generated by bacteria in the water, the bacteria that secrete the EPS, and debris entrapped in the biofilm.

- **Cycles of Concentration:** Also referred to as concentration ratio, it relates to the number of times that minerals in the cooling tower water are concentrated with respect to the same minerals present in the make up water. There are several ways of calculating the concentration ratio in an evaporative cooling system, but the two most commonly used are by conductivity or by volumetric ratio (both are explained in detail further in this report).
- **Evaporation (Ev):** Refers to the volume of water loss as a result of evaporation from the evaporative cooling system. Evaporation (Ev) can be calculated by the equation:

$$Ev = dT_{CT} \cdot Q \cdot 0.00085$$

where:

EV = evaporation rate in gpm
dT_{CT} = design delta T of the Cooling Tower in °F
Q = recirculation rate in gpm

- **Blow Down (BD):** The volume of water intentionally discharged from the evaporative cooling system to maintain a desired concentration ratio. BD is calculated based on the evaporation rate and the cycles of concentration, through the following equation:

$$BD = Ev/(C-1)$$

where:

BD = blow down volume in gpm
Ev = evaporation rate in gpm
C = cycles of concentration

- **Make Up (MU):** The volume of water added to the cooling tower to compensate for the evaporation and blow down, expressed as follows:

$$MU = Ev + BD$$

where:

MU = make up water volume in gpm
Ev = evaporation rate in gpm
BD = blow down volume in gpm

- **Conductivity:** A measurement of the concentration of dissolved minerals in the water, measured in microsiemens (µS). In evaporative cooling systems it can also be referred to as Total Dissolved Solids (TDS), which is measured in parts per million (ppm).
- **Conductivity Controller:** Electronic instrumentation that measures the conductivity in the re-circulating water within the evaporative cooling system and opens a solenoid valve to allow the discharge of the Blow Down, maintaining a certain concentration ratio in the system.

3.2 Traditional water treatment

Water treatment or water conditioning using chemical additives has been in practice for many decades and there are numerous proprietary products that have been developed. Most operators of water-based cooling equipment are thoroughly familiar with application techniques and the expected results from the use of specialty chemicals. Environmental concerns, along with health and safety considerations, have limited the number and type of chemicals in use and have placed regulatory limitations on using some of the more effective specialty chemical formulations.

Chemical control of fouling may employ a range of chemical additives such as the following:

- acid for pH control
- dispersants to regulate scale forming components in the water
- corrosion inhibitors to control metal destruction
- biocides to kill bacteria.

Conventional measures taken to control scale start with operating at a low concentration ratio, followed by chemical scale inhibitor treatment, pH adjustment by acid addition, or softening of cooling water system MU.

Chemicals are usually applied on a continuous basis, require secure storage, and are handled as hazardous materials. Chemically treated systems require large amounts of blow down to be discharged in order to maintain low cycles of concentration. This discharge carries with it the chemicals applied as part of the treatment program, making it a very inefficient approach from the standpoint of chemical waste and water conservation. If not secured and administered properly, these chemicals present a risk to the equipment, equipment operators, and the environment. The continual application of chemicals represents an ongoing expense for materials and is also labor intensive.

A chemical-based water treatment approach assumes that there is little or no variation in the composition of the MU water to the system. Based on this assumption, the chemical feed pumps are set to add chemicals at a certain rate. In actuality, there are many locations where the chemical composition of the MU water varies seasonally, and in some locations it even varies daily. If the chemical feed pump settings are not adjusted for these changes, the amount of chemicals may under-feed, potentially resulting in scaling or corrosion, or over-feed, resulting in unnecessary waste and expense.

3.3 Scale formation

Depositing of scale is a chemical precipitation process where dissolved salts in the cooling water precipitate out of the bulk water because their solubility limits have been exceeded. The most common scale formers, calcium salts, exhibit reverse solubility with respect to the temperature of the water and/or the pH (less soluble at higher temperatures and/or higher pH). This condition results in scale formation in the most sensitive heat transfer surfaces of production equipment.

Since the thermal conductivity of scale is substantially less than metal, heat removal from the equipment is reduced when scale forms. In extreme cases, enough material is deposited on surfaces to physically block the cooling water, resulting in the affected equipment being removed from service for either chemical (acid) or mechanical cleaning.

In the condenser of an HVACR chiller, scale deposits cause an increase in the condensing temperature of the refrigerant gas, which results in an increase in the energy required to compress the refrigerant at that higher temperature. Figure 3 illustrates the effect of condenser-tube scale on compressor energy consumption in a chiller.[3]

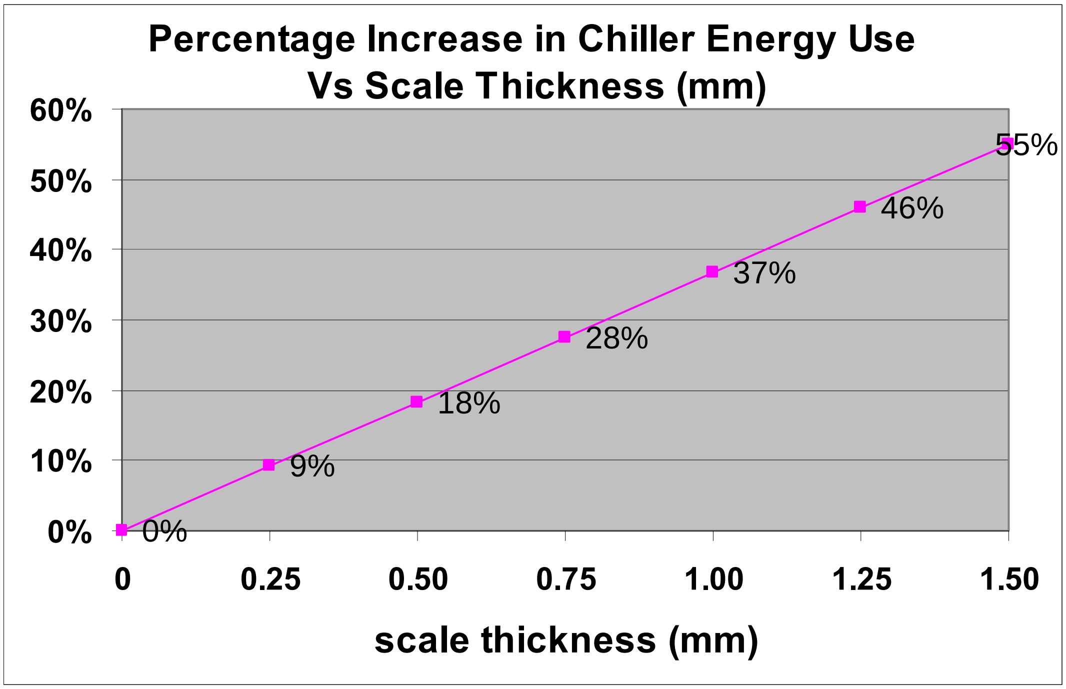

Figure 3. Effect of scale on energy use in a chiller.

3.4 Scale monitoring

The scaling potential of water can be evaluated by visually looking for signs of scaling or by monitoring the coefficient of performance (COP) of the heat exchangers. Langelier's Saturation Index (LSI) is a calculation that utilizes the levels of calcium, alkalinity, pH, dissolved solids, and temperature in the cooling water to indicate a potential for calcium scale formation (positive LSI), or a potential to dissolve scale and promote corrosion (negative LSI).

It is important to note that LSI analysis indicates only a "potential" for scaling or corrosion. The LSI method is used with chemical programs because when salts exceed their solubility limits (positive LSI), scaling is likely to occur. This does not indicate that scaling is taking place, but instead, that bulk precipitation of salts from the solution is likely. In order to check if scaling is taking place, it is necessary to conduct physical tests.

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[3] The data to generate the graph in Figure 3 was taken from: "Water Treatment for HVAC & Potable Water Systems" by R.T. Blake, McGraw Hill.

Physical tests can be made by closely observing certain operating parameters in the cooling system. For cooling tower-chiller applications, the condenser approach is a good indication that scaling (although it could be some other form of fouling) is taking place in the condenser tubes. In plate and frame types of heat exchangers, a decrease in the temperature differential (dT) or pressure differential (dP) across the unit can be indicative of fouling of the unit. In evaporative condensers, an increase in the discharge pressure of the refrigerant is related to scaling of the tube bundle. These methods will detect potential fouling in the key elements of a cooling system (i.e., the heat exchangers). Due to easy access to the tube bundle of evaporative condensers, it is a relatively simple matter to visually inspect these units for scale formation.

3.5 Corrosion

Water, while an excellent transporter of heat, can be an aggressive oxidizing agent causing severe corrosion to most metals used in the construction of evaporative cooling systems. The chemistry of all cooling water treatment programs must begin by addressing corrosion, which is an electrochemical oxidation process that results in destruction of the basic metals from which most cooling systems are constructed.

Many factors affect the uncontrolled corrosion rates which could be expected in any given cooling water system. Items such as the presence of dissolved gases, chloride and sulfate levels, pH, alkalinity, scaling tendency, protective ions, and phosphate and nitrate, must all be taken into consideration; others include engineering factors such as water temperatures, presence of galvanic couples, and water velocity in the design of equipment.

Microbially Induced Corrosion (MIC) is another type of corrosion that is not related to dissimilar metals, pH of the water, or oxidation. This type of corrosion takes place when anaerobic bacteria form a biofilm on metal surfaces. These types of bacteria—iron-reducing bacteria (IRB) and/or sulfur-reducing bacteria (SRB)—can cause pitting, which may lead to premature tube failure and can be much more aggressive and damaging than general corrosion.

3.6 Corrosion monitoring

The most common method of monitoring for corrosion is by inserting corrosion-test coupons into the cooling water loop. This corrosion-test method has been described by the National Association of Corrosion Engineers (NACE) and is consistent with the ASTM D2688, "Corrosivity Testing of Industrial Cooling Water (Coupon Test Method)."[4]

The method consists of exposing a pre-weighed test coupon in the recirculating water system for a given period of time (90 days is recommended). The corrosion rate is then calculated on the basis of the weight loss of the test coupon, the coupon's surface area, and the exposure time. The corrosion rate is expressed in mils per year (mpy) of metal loss.

Table 1 shows the acceptable corrosion levels for carbon steel and copper alloy as set by NACE. These two metals are the most commonly found in HVACR systems. The piping of the system typically consists of mild steel pipe, whereas the tubes in heat exchangers are made out of a copper alloy.

Table 1. Quantitative classification of corrosion rates for open re-circulating cooling water systems (NACE)

Corrosion Rates (mpy)		
Description	Carbon Steel	Copper Alloy
Negligible or Excellent	≤ 1	≤ 0.1
Mild or Very Good	1-3	01.-0.25
Good	3-5	0.25-0.35
Moderate to Fair	5-8	0.35-0.5
Poor	8-10	0.5-1.0
Very Poor to Severe	>10	>1.0

A second method of evaluating corrosion is the use of electronic corrosion rate meters,[5] which are fairly accurate and quite useful in many cases, but are substantially more expensive than corrosion coupons. These meters are more commonly found in chemical processing and petrochemical plants where the fluids being transported through the pipes have a high corrosion potential.

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[4] National Association of Corrosion Engineers (NACE), "Standards for Corrosion Rates" by Bennett P. Boffardi Ph.D.

[5] See Appendix B for more information on the electronic corrosion probes and transmitters used in this study.

A third method is to measure the concentration of total iron in the re-circulating water (i.e., 0.1-0.2 ppm is normal; 0.5-1.0 is excessive; >1 ppm is cause for alarm).

3.7 Biofouling

Open, re-circulating water systems are continually exposed to the ambient air and its contaminants. One category of contaminants consists of micro-organisms that will grow in water under favorable circumstances. These organisms may be slime-forming bacteria, fungi, or algae; they are present in the atmosphere, attached to dust and dirt particles, and swept into re-circulating water systems by air movement.

Microorganisms may be controlled by killing them with biocides, causing minimum damage to the material used in constructing the cooling system. Chlorine or bromine-based products are some of the most common biocides currently being used. The two main problems associated with biocides are related to their limited effect and to environmental regulations.

Once bacteria enter a re-circulating water system, they will begin to adhere to the surfaces of the equipment and form colonies defined as biofilms. Biofilms are a complex matrix of different types of bacteria protected by an exo-polysaccharide (EPS) generated by slime-forming bacteria. The EPS gives biofilm its slimy texture and has several functions—notably to provide a protective layer for the bacteria and a means to channel nutrients and waste between bacteria colonies. Bacteria growth takes place within the biofilm and not while the bacteria are in their pelagic (free-floating) stage (Romo, Pitts, and Hector 2002; Romo and Pitts 1999, 2000; Romo, Pitts, and Handagama 2007).

It is within the biofilm that the biocides are rendered inefficient. Biocides are designed to kill bacteria, but not to prevent the formation or cause removal of existing biofilms. Because biocides cannot kill all the bacteria when biofilms are present, the bacteria population constantly experiences rapid re-growth despite the continuous use of biocides or frequent biocide “shocks” applied to the system. There is another critical problem with biofilms: They are the place where harmful bacteria reside and multiply. Bacteria such as *legionella pneumophila* and other pathogens that can cause respiratory illnesses are not slime-forming bacteria, but require the presence of a biofilm within which to establish colonies. Biofilms are also the cause for MIC which causes severe pitting damage in the system. Iron-and sulfur-reducing bacteria may colonize the lower areas of the biofilm where an anaerobic environment is created. These bacteria will feed from the carbon in the steel and generate hydrogen sulfide as a by-product which, in turn, converts to sulfuric acid in the presence of water.

The handling, storage and disposal of biocides are problematic. Regulations restrict the types and amounts of biocide that cooling plants are allowed to discharge, and additional wastewater processing charges often apply.

3.8 Monitoring biofouling and bacteria

Test methods are available for monitoring the re-circulating water for bacteria. These methods include test strips, or dipsticks, that are used to obtain a total bacterial count. Tests made periodically during operation of the cooling system will provide a history indicating whether there is an increase in the bacterial count during any particular season. These tests are also used to determine the effectiveness of a biocide program and to indicate when treatment should be changed or altered.

Opinions differ regarding acceptable limits of bacteria in a re-circulating water system. McCoy (1983) indicates that viable plate counts are seldom obtained for less than 10,000 colony-forming units per milliliter (cfu/ml), even when measured immediately after treatment with biocide, due to the constant inoculation of the system. Counts of 100,000 – 500,000 cfu/ml ($1x\ 10^5$ – $5x10^5$) indicate a biologically clean system, and when counts exceed $1x10^6$, a biocide shock is warranted.

Freije (1996) indicates that the bacteria counts on the test are an indication of the general cleanliness of a cooling tower, but they do not indicate legionella levels. Monthly dip-slide tests are recommended to ensure that total bacteria counts remain under $5x10^5$ cfu/ml.

3.9 Sludge

Deposits of mud, dirt, and foreign suspended matter that are washed out of the atmosphere (sludge) into open re-circulating-water systems can be as troublesome as scale. These deposits must be controlled to ensure efficient operation of heat transfer equipment. The amount of sludge accumulated in a cooling system varies from location to location and is relative to the environment in which the cooling tower is found. Visual inspections of the basin of the cooling tower will allow plant personnel to determine, or quantify, the amount of sludge build-up in the system and the frequency with which the tower will need to be cleaned. Cleaning is recommended at least annually; however, there are locations that require more frequent cleanings. Some plants have installed side-stream filtration units to constantly remove sludge-forming matter.

3.10 Water Conservation

Cycles of concentration determine the degree to which water is recycled in an evaporative cooling system (i.e., the number of times that the dissolved salts in the fresh make-up water (MU) are concentrated by evaporation from the cooling system). This can be measured in several ways, but the three most common methods are as follows:

1. **By conductivity or total dissolved solids (TDS):** The cycles of concentration (C) are equal to the ratio of the conductivity (or TDS) in the re-circulating water (RW) to the conductivity (or TDS) of the make-up water (MU). This can be expressed by the following equation:

$$C = TDS(RW) / TDS(MU)$$

Conductivity meters and/or Total Dissolved Solids (TDS) meters are used to make the measurement. Conductivity meters measure the amount of salts dissolved in the water in micro siemens (µs); TDS meters measure the amount of dissolved solids in the water in parts per million (ppm). A conductivity set-point (based on the average conductivity of the MU water) is selected, and the controller is programmed to open a solenoid valve when the conductivity in the re-circulating water reaches the set-point.

2. **Volumetric Ratio:** Cycles of concentration can be measured as the ratio of make-up water (MU) to blow-down water (BD). In systems equipped with cumulative water meters for MU and BD, the cycles can be calculated as the amount of water added to the tower (by MU) divided by the amount of water purged from the tower (through BD). This is expressed by the following equation:

$$C = (MU) / (BD)$$

This is the preferred method for cycle control when operating at high cycles of concentration (i.e., above 3.5). At high cycles of concentration, mineral precipitation occurs and with that, the linear relationship between conductivity in the water and true cycles is lost. Therefore, by maintaining a volumetric ratio, one can ensure that true cycles are maintained in the system. The controller will measure a given volume of MU water and then open a solenoid valve; the BD meter measures a pre-programmed volume of water to maintain the volumetric ratio, which corresponds to the cycles of concentration desired.

3. **Highly soluble ions:** When towers run at high cycles, some of the ions that are measured with conductivity and TDS meters go from solution to suspension (they precipitate). When this happens, the cycles measured by conductivity or TDS do not reflect the true cycles of the tower. There are certain ions that are much more soluble (they do not precipitate) and thus, the cycles can be measured as the ratio of those ions in the circulating water to their concentration in the make-up water. The most commonly used ion is chlorides; however, in towers where sodium hypochloride (or other chlorinated compounds) are used as a biocide, it can affect the level of chlorides in the re-circulating line.

The goal of operating the tower at higher concentration ratios is to reduce the overall amount of water used in the evaporative cooling system. This is accomplished by reducing the amount of BD discharged and thereby reducing the required MU by the same amount. This results in reduced water usage, and a corresponding reduction for the cost of fresh water and sewage disposal. These reductions may be significant, as illustrated by Figure 4 and Figure 5.[6]

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[6] The graphs were produced as a result of equations used to calculate evaporation rate, blow down, and make up of an evaporative cooling system from "Perry's Chemical Engineers' Handbook" (see reference list.)

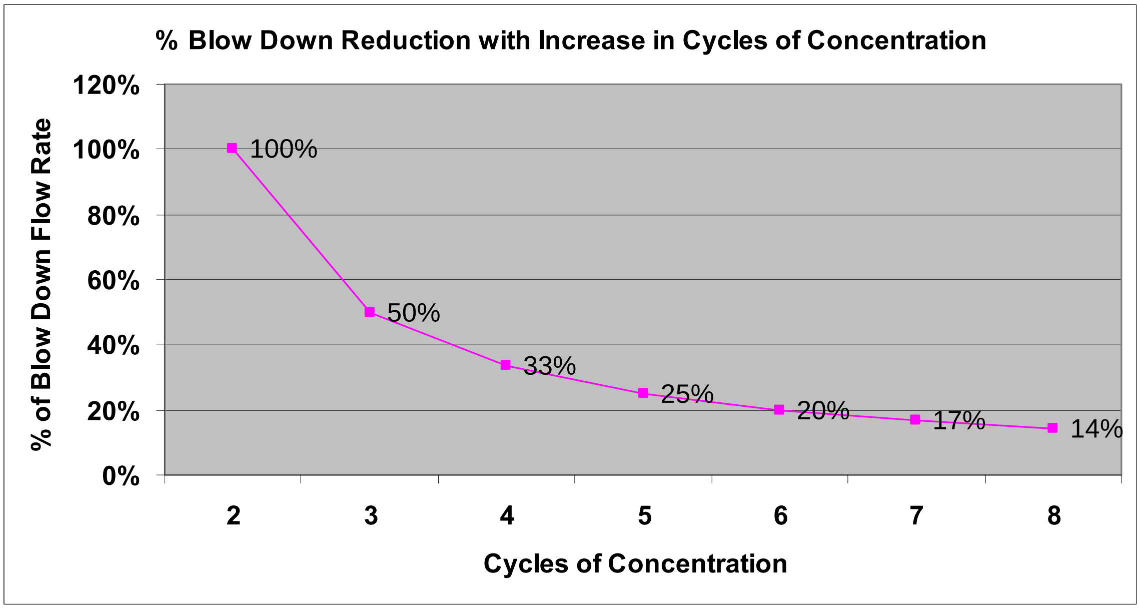

Figure 4: Percentage blow-down reduction with increase in cycles of concentration.

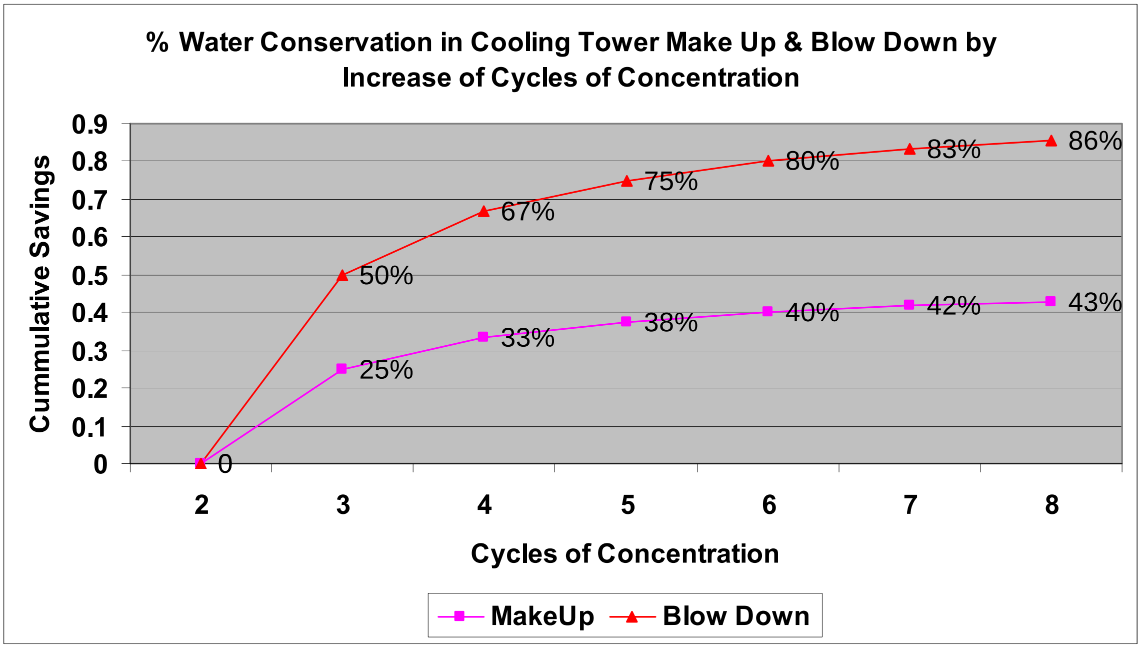

Figure 5: Percentage of water conservation in cooling tower make-up and blow-down, by increasing cycles of concentration.

4 Technology

4.1 Capacitor-based colloidal dispersion

Electrostatic dispersion of colloidal particles applies theories from colloidal physics and colloidal chemistry[7] to produce a strong electrostatic dispersion of colloidal particles in a fluid. This is accomplished by forming a capacitor within a water system. A strong electrostatic field and corresponding capacitor is created by inserting an insulated electrode into a grounded pipe or vessel. Numerous papers have been presented to engineering conferences or published in peer-reviewed journals that discuss in detail the principles of operation of the technology (Pitts 1992, 1995; Romo, Pitts, and Hector 2002; Romo and Pitts 1999, 2000; and Romo, Pitts, and Handagama 2007).

The conductive lining of the ceramic electrode serves as one plate of the capacitor. The dielectric strength of the vitrified ceramic material that comprises the electrode prevents current flow to the other plate of the capacitor. The grounded plane of a cylindrical capacitor is established by the metal of the pipe or vessel into which the rod is inserted (Figure 6).

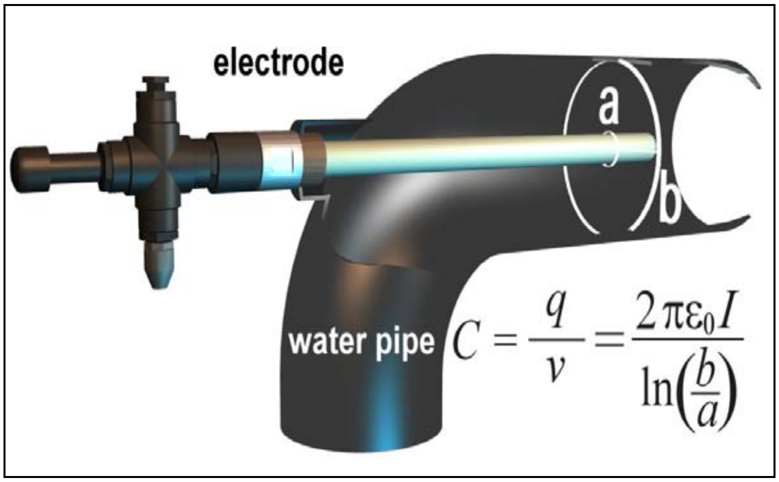

Figure 6: Cutaway view of the cylindrical capacitor created by the electrode and the pipe wall. The electrode forms the cathode of the capacitor, and a grounded metal pipe or vessel forms the anode.

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[7] These theories include the Derjaguin, Landau, Verwey and Overbeek (DLVO) theory, and the Double Layer theory.

A direct current power supply charges the capacitor system to a very high potential (normally 30–35 kV DC). The field strength between the plates of the capacitor is a function of charge voltage, dimensions of the equipment to be treated, and the dielectric constant of the ceramic.

Characteristic of a capacitor, there is no electrical current flowing across or through the ceramic body of the electrode and into the water. Operating costs for the power supply are negligible, with power consumption at less than 5 W. The maximum current output of the power supply is 600 µA (just over .5 mA).

The electrostatic field reduces the surface tension of water and boosts the surface charge of colloidal particles and wetted surfaces (Figure 7). Particles suspended in the water are caused to repel one another and to be repelled from other wetted surfaces. Through these physical effects, particles and bacteria that would otherwise combine to form scale or biofilms are dispersed and the potential for fouling is mitigated.

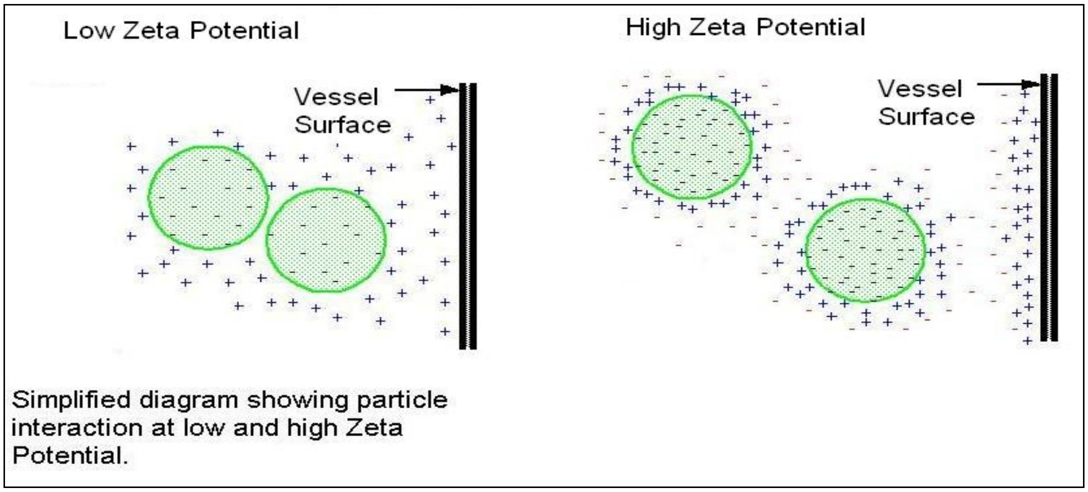

Figure 7. Particle interaction at low and high Zeta potential.

With particle agglomeration controlled, cooling water can be evaporated to high concentrations of dissolved solids. The capacitor-based system, combined with instrumented monitoring, is able to support high levels of water use efficiency, while assuring system stability with reduced labor inputs and minimum energy consumption.

4.2 Fouling and corrosion controlled by particle dispersion

Unlike a chemical program, the capacitor-based system is able to approach the problems of fouling in cooling water systems by treating fouling at the source, rather than by controlling only the symptoms. By producing a treatment based on the alteration of the physical properties of colloidal particles, this technology is not affected by variations in the chemical composition of the MU water; therefore there is no risk of over-feeding or under-feeding a chemical product into the system.

Biofilms supply the foundation for scale to adhere, and they provide a secured hiding place for bacteria and resulting MIC. The electrostatic charge imparted to wetted surfaces disrupts the bonding capacity of a biofilm, thereby forcing the clearing and flushing of biomass from the tower system by the turbulence of the flow.

Without the addition of acid, the chemical buffer capacity of the water elevates the pH to 8.9–9.0, and the water analysis presents highly positive LSI details. As stated earlier, a positive LSI is indicative of a high potential for scaling, but presents little or no corrosion potential. With a positive LSI and a pH level of 8.9–9.0, corrosion rates are minimal for mild steel and copper alloys.

Application of electro-static colloidal dispersion techniques, even under conditions of high scaling potential, offers an indirect corrosion control technique, using well-understood chemical relationships.

4.3 Water conservation by volumetric control

The composition of dissolved minerals in most water supplies varies over time, and the variance may occur seasonally or daily. The demonstration technology of this project brings water chemistry effects into consideration, but focuses the management of bleed rates for water conservation by volumetric standards, rather than by conductivity control.

At high concentration ratios, shifting from conductivity measurement to volumetric control avoids the unpredictable operating variance associated with conductivity, and true cycles of concentration can now be measured. Water meters are installed on pipes of the MU water and bleed lines. Electronic control units record flow data and control the bleed valve.

Volumetric control of blow down provides accurate measurement of water usage and sewer discharge volumes, thereby allowing for direct calculation of cumulative water cost savings and proof of water conservation. It also ensures that true cycles are maintained in the system regardless of changes in the chemical composition of the make up water.

5 Field Demonstration

Comparable evaporative cooling systems of two types (cooling towers and evaporative condensers) that share similar environmental and water quality conditions were chosen at two military installations. Data points were defined and sample gathering protocols were established. Matching instrumentation sets were installed to complement the manual water testing and visual examinations to be performed.

Care was taken to assure unbiased and untainted data collection. All site work was observed by base personnel, CERL's appointed representative, and Zeta personnel. The chain of custody was secured during sampling, and independent laboratories were chosen for testing of water samples, bacteria count determinations, and corrosion coupon analyses. The chemical treatment providers[8] had no unsupervised access to the Zeta installations, and Zeta personnel had no unsupervised access to the chemically treated systems. The chemical treatment providers continued to run the control sites in the manner dictated by their respective service contracts, knowing that their results were being monitored.

5.1 Site selection, timeline

Fort Huachuca, an Army installation, and Davis Monthan Air Force Base, both located in southern Arizona, were selected in May 2007 as sites for demonstration and evaluation (DEM/VAL) of the Zeta Rod technology.

At Fort Huachuca, two cooling tower and chiller facilities were chosen — the North Central Plant (chemical treatment control site) and the South Central Plant (technology demonstration site).

The evaporative cooling equipment chosen at Davis Monthan AFB consisted of two similar evaporative condensers, providing comfort cooling to a fitness center (Building 2301) and to a dormitory on the base (Building 3750). The fitness center equipment was selected to demonstrate the technology, while the dormitory complex was selected to be the control site and remain under the existing chemical treatment program.

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[8] Chemtreat, Inc. served Fort Huachuca; GE Betz, Inc. served Davis Monthan AFB.

On July 7, 2007, installation of equipment at both military bases was completed and the program was activated. The chemical feed to the two Zeta Rod installations was discontinued. Existing scale from tubes on the Zeta treated condenser at Davis Monthan AFB was collected, and sections of the tubes were cleaned and marked for follow-up inspection. At Fort Huachuca, a borescope contractor inspected and videotaped selected tubes on chillers at both plants.[9]

Initially, all four systems were set to operate under the same cycles of concentration as they had been traditionally operated. These conditions were typical of conditions encountered in most chemically treated evaporative cooling systems. During the first 6 months, cycles remained at these levels and served to establish a baseline on the performance of the technology vs. chemicals. After the initial 6 months, the concentration ratio was adjusted upward on the Zeta treated sites to facilitate the water conservation demonstration. The technology demonstration period covered by this report was 16 months, covering two complete high-demand cooling seasons.

Corrosion coupons were installed and monthly visits were conducted, during which water samples and bacteria detection slides were exposed and delivered to an independent lab for analysis (Appendix A).[10] Every 90 days, corrosion coupons were removed and sent for weight loss analysis.[11] During the monthly site visits, visual inspections and photo documentation were recorded of the condenser tubes on the Zeta treated cooling system at Davis Monthan.

Borescope inspections of condenser tubes at Fort Huachuca were performed in December 2007 and October 2008 during the last visit to the facility.

During May 2008, the remote monitoring system design developed for the program was completed and installed on the two Zeta treated systems. Real-time monitoring of the cooling tower water treatment and control was instituted through a wireless communication Internet web portal. The monitoring system also had the capability of sending alarm messages in the event that any of the pre-set parameters were out of specified ranges.

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[9] Arizona Borescope, LLC, Marana, Arizona

[10] Turner Laboratories, Inc., Tucson, Arizona

[11] Metal Samples Co., Inc., Munford, Alabama, ASTM-G1 specifications.

5.2 Water management remote monitoring

The wireless remote monitored water management system[12] had the following components for tracking cooling water status:

- data logger/controller
- Zeta power supply with alarm signal generator
- volumetric ratio bleed controller
- corrosion probe and signal transmitter
- wireless router and cellular communications hardware (or hard data line)
- conductivity control capability.

Real-time monitoring of cooling system status was accomplished with Web access to the data controller and software that allows adjustments to the system to be made via computer (Figure 8). The control and monitoring components were installed at all four sites, whereas the remote monitoring and communications package was only installed on the technology demonstration sites.

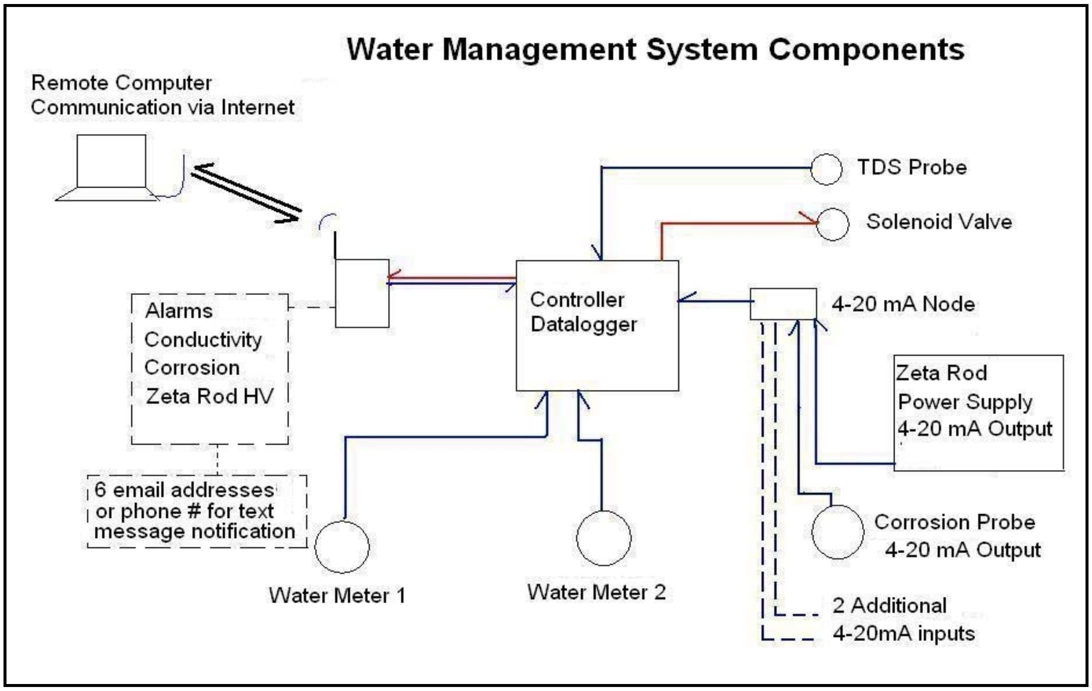

Figure 8. Water management system components developed for wireless remote control.

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[12] Zeta Corporation worked with Lakewood Instruments to develop the wireless capabilities of the management system, which had not been developed previously.

5.3 Fort Huachuca, South Central Plant: Technology demonstration site

The South Central Plant had three chillers. Two chillers shared a two-cell cooling tower with a common basin. The third chiller operated independently with its own cooling tower. Chillers 1 and 2, with their common cooling tower water flow, served as demonstration chillers for the study. The South Central Plant had a thermal storage tank for chilled water storage.

South Central cooling equipment:

- Chiller 1: Carrier Model 10XB44003501
- Chiller 2: Carrier Model 10XB44003501

The South Central Plant was also equipped with a data logging bleed controller to measure flow volumes and conductivity. An existing corrosion coupon bypass rack with three positions was utilized. Mild steel and copper coupons were placed in the bypass, along with the electronic corrosion metering probe. Data from this probe was also collected by the conductivity controller and data logger.

The electronic capacitor-based system for this demonstration location consisted of three ceramic electrodes (Model ZR36S Zeta Rods) powered by a 35Kv DC power supply (Zeta model ZRPGM). Each of the two chillers had a rod installed in the condenser water supply line; the third rod was installed in the condenser water return common header (Figure 9).

New water meters were procured and installed at this location in the MU and BD lines in order to monitor water consumption.

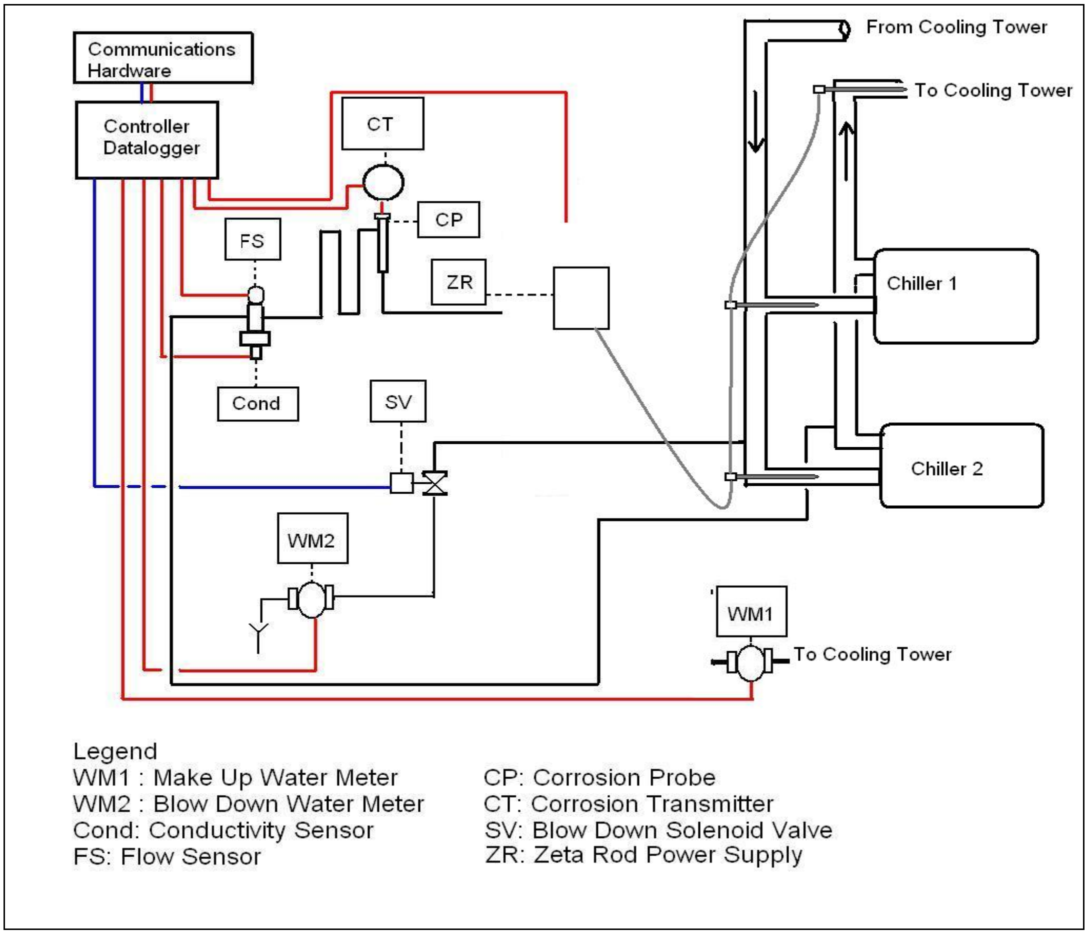

Figure 9. Zeta water management system installed at Fort Huachuca, South Central Plant.

5.4 Fort Huachuca, North Central Plant: Chemical treatment control site

The three chillers of the North Central Plant were served by a three-cell cooling tower; a common cool-water basin and a 10-in. line supplied cooling water to each of the chiller/condensers. Common header piping returned warm water from the chillers back to the cooling towers, and chilled water from the plant cooled water that accumulated in a large thermal storage tank. The chillers operated during low-demand hours throughout the night to load the thermal storage tank for the daytime cooling operation.

North Central cooling equipment:

- Chiller 1: Trane Centravac Series R, 425 RT.
- Chiller 2: Trane Centravac Series R, 425 RT
- Chiller 3: Carrier Centrifugal model 02XR-341CE S64.

Cycles of concentration were controlled via an existing Pulsatrol® conductivity controller (Model MCT-230), which monitored conductivity in the re-circulating water as well as pH levels. The BD set-point was found to be 1000 µs. The Fort Huachuca domestic water MU source had an average conductivity of 335 µs, which set the concentration ratio for this system at 2.98 cycles of concentration (as determined by conductivity).

5.5 Davis Monthan AFB, Fitness Center Bldg. 2301: Technology demonstration site

The Fitness Center Building 2301 cooling equipment was an EVAPCO 110TR evaporative condenser with a ¾-in. BD line and a ¾-in. MU line, neither of which was fitted with a water meter. Conductivity was historically controlled with a Lakewood Instruments conductivity controller (Model 151/161) and maintained a set point of 1000 µs. There were no corrosion coupons installed on this unit, and no historical records were provided for bacteria counts or corrosion rates. This system was elected as the demonstration site for the Zeta technology, which consisted of a single Zeta Rod and power supply.

The new controller was set to control cycles of concentration (based on conductivity), with an initial set-point of 1,000 µs, to maintain the prior operating parameters. The MU water at this location had an average conductivity of 344 µs, meaning that the tower was set to operate at 2.9 cycles of concentration. Figure 10 illustrates the components of the Zeta Water Management System installed at this facility.

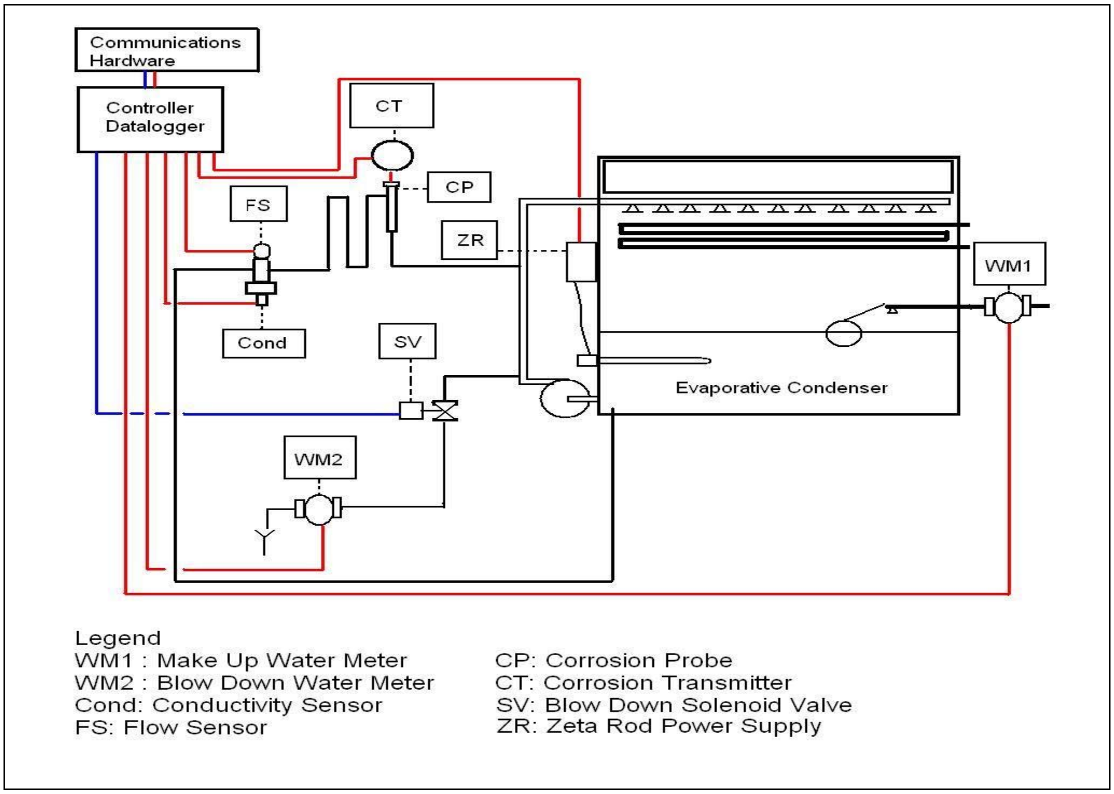

Figure 10. Demonstration site diagram for Fitness Center Building 2301 at Davis Monthan AFB.

5.6 Davis Monthan AFB Dormitory Bldg. 3750: Chemical treatment control site

Dormitory Building 3750 was cooled by a McQuay evaporative condenser (120 TR). The BD traveled through a ½-in. pipe and MU through a ¾-in. pipe; neither line was equipped with a water meter. Conductivity was controlled via an existing Aquatrac Microflex (part # CO-IN) controller. However, as indicated by the settings on the unit, circulating water conductivity was controlled by a conductivity/timer arrangement rather than a conductivity set-point. The conductivity of the system at the initial site visit was 890µs, which indicated a concentration ratio that approximated two cycles of concentration. Over the duration of this DEM/VAL, the conductivity in this unit varied from 390 µs to 1,300 µs, with an average of 746 µs (equivalent of 2.1 cycles of concentration).

6 Data

6.1 Fort Huachuca data results

Fort Huachuca data showed this location's MU water quality remained fairly stable throughout the period of the DEM/VAL, showing little or no seasonal variation (Table 2). The MU water is obtained from the Sierra Vista, Arizona municipal water supply and averaged 335 µs in conductivity. The cooling tower water was analyzed monthly (Table 3 and Table 4).

Table 2. Fort Huachuca – make-up water supply analysis.

Fort Huachuca
Make-up Water Supply Analysis

Month	Alkalinity Bicarbonate	Alkalinity Carbonate	Alkalinity Total	Conductivity	Hardness (CA)	Hardness (CA / MG)	Chloride	Iron	Copper
Jul 07	150	ND	150	340	97	130	8.4	ND	ND
Aug 07	150	ND	150	330	100	130	7	ND	ND
Sep 07	160	ND	160	330	100	140	6.8	ND	ND
Oct 07	150	ND	150	320	95	120	7.4	ND	0.026
Nov 07	Sampling or labeling error resulted in no data for make-up water samples.								
Dec 07	150	ND	150	360	92	130	12	ND	ND
Jan 08	140	ND	140	340	100	130	6.5	ND	0.068
Feb 08	160	ND	160	350	100	140	6	ND	ND
Mar 08	160	ND	160	340	95	130	7.1	ND	ND
Apr 08	160	ND	160	330	97	130	6.7	0.006	0.006
May 08	150	ND	150	320	90	120	6.5	ND	0.023
Jun 08	150	ND	150	320	90	120	8.5	0	0
Jul 08	140	ND	140	340	100	140	9.8	0	0
Aug 08	140	ND	140	320	92	120	6.9	0	0
Sep 08	150	ND	150	340	100	140	12	0	0
Average	**150**		**150**	**335**	**96**	**129**	**8**	**0.001**	**0.011**

Table 3. Fort Huachuca - Zeta demonstration site (South Central Plant) – cooling tower water analysis.

Fort Huachuca
Zeta Demonstration Site (South Central Plant) -
Cooling Tower Water Analysis

Month	Alkalinity Bicarbonate	Alkalinity Carbonate	Alkalinity Total	Conductivity	Hardness (CA)	Hardness (CA / MG)	Chloride	Iron	Copper
Jul 07	400	130	520	980	320	460	34	ND	ND
Aug 07	290	130	420	980	85	280	48	0.57	ND
Sep 07	260	120	380	930	75	250	48	ND	ND
Oct 07	260	140	400	940	67	230	49	ND	ND
Nov 07	210	80	290	690	82	190	30	ND	ND
Dec 07	180	56	230	620	67	180	37	ND	ND
Jan 08	170	82	250	680	87	200	33	ND	ND
Feb 08	190	80	270	640	90	190	24	ND	ND
Mar 08	240	96	340	840	77	240	43	ND	ND
Apr 08	260	100	360	900	77	240	47	ND	0.006
May 08	180	80	260	630	77	180	25	ND	ND
Jun 08	230	92	320	750	80	220	40	ND	ND
Jul 08	200	92	290	810	82	220	42	ND	ND
Aug 08	210	100	310	810	85	220	41	ND	ND
Sep 08	220	96	320	890	85	250	54	ND	ND

Table 4. Fort Huachuca - chemical treatment site (North Central Plant) – cooling tower water analysis.

Fort Huachuca
Chemical Treatment (North Central Plant) -
Cooling Tower Water Analysis

Month	Alkalinity Bicarbonate	Alkalinity Carbonate	Alkalinity Total	Conductivity	Hardness (CA)	Hardness (CA / MG)	Chloride	Iron	Copper
Jul 07	380	160	540	950	350	470	26	ND	ND
Aug 07	340	220	560	860	320	450	28	ND	ND
Sep 07	350	180	530	930	320	440	24	ND	ND
Oct 07	350	190	540	970	350	450	26	ND	ND
Nov 07	370	180	550	990	300	400	28	ND	ND
Dec 07	310	150	460	950	270	390	35	ND	ND
Jan 08	330	160	490	940	300	410	30	ND	ND
Feb 08	320	180	500	980	320	440	29	ND	ND
Mar 08	310	230	540	1200	300	450	40	ND	ND
Apr 08	230	110	340	680	47	120	17	ND	ND
May 08	170	340	500	1300	77	120	43	0.72	0.43
Jun 08	180	320	500	1300	80	120	44	0.77	0.47
Jul 08	180	290	470	1300	82	120	40	0.5	0.74
Aug 08	290	240	530	1000	300	430	36	0	0
Sep 08	330	200	530	990	350	480	35	ND	0.02

Initially, the concentration ratio at both plants was controlled by conductivity, with a set-point of 1,000 μs or approximately 3 cycles of concentration. The chemical system data displayed consistent concentration levels over the measurement period.

There were discrepancies in cycles of concentration measured by conductivity, compared to cycles measured by volumetric ratio (Table 5). While the concentration ratio remained at 3 cycles, as controlled by the set-point of the controller, volumetric ratio showed true ratio to be closer to 7 cycles. This discrepancy occurs when minerals in the re-circulating water begin to precipitate and come out of solution. In December 2007, the concentration ratio of the cooling system in the South Central Plant (Zeta) was switched from control-by-conductivity to control-by-volumetric ratio.

Following the transient period where start-up cycles of concentration exceeded the planned set-point at the technology demonstration site, a follow-up borescope was performed in December 2007 on both systems. The borescope indicated no differences from the initial July 2007 inspection for any of the tubes in the chemically treated condenser or in the condenser that had been treated with the demonstration technology. A final borescope inspection in October 2008 corroborated once again that no scaling had taken place in condensers at either of the two sites.

In February 2008, adjustments were made at the technology demonstration site to increase the concentration ratio to 6 cycles of concentration by volumetric ratio control, in order to initiate the water conservation demonstration.

Table 5. Fort Huachuca, cycles of concentration data.

Fort Huachuca
Cycles of Concentration Data

South Central Plant - Zeta Treated						North Central Plant - Chemically Treated					
Month	Conductivity	Hardness	Alkalinity	Chlorides	by Volume	Month	Conductivity	Hardness	Alkalinity	Chlorides	by Volume
Jul 07	2.88	3.54	3.47	4.05	6.40	**Jul 07**	2.88	3.62	3.86	3.71	4.09
Aug 07	2.97	2.15	2.80	6.86	7.40	**Aug 07**	2.61	3.46	3.73	4.00	4.17
Sep 07	2.82	1.79	2.38	7.06	7.11	**Sep 07**	2.82	3.14	3.31	3.53	4.20
Oct 07	2.94	1.92	2.67	6.62	6.90	**Oct 07**	3.03	3.75	3.60	3.51	4.11
Nov 07	ND	ND	ND	ND	6.90	**Nov 07**	ND	ND	ND	ND	4.11
Dec 07	1.72	1.38	1.53	3.08	3.75	**Dec 07**	2.64	3.00	3.07	2.93	4.18
Jan 08	2.00	1.54	1.79	5.08	3.68	**Jan 08**	2.76	3.15	3.50	4.62	4.07
Feb 08	1.82	1.35	1.68	4.00	6.00	**Feb 08**	2.80	3.14	3.13	4.80	4.04
Mar 08	2.47	1.84	2.13	6.05	5.60	**Mar 08**	3.52	3.46	3.37	5.63	4.54
Apr 08	2.72	1.84	2.25	6.86	6.43	**Apr 08**	2.06	0.92	2.13	2.53	4.78
May 08	1.97	1.50	1.73	3.85	5.97	**May 08**	4.06	1.00	3.33	6.62	4.63
Jun 08	2.34	1.83	2.13	4.71	5.98	**Jun 08**	4.06	1.00	3.33	5.87	4.49
Jul 08	2.38	1.57	2.07	4.29	5.85	**Jul 08**	3.82	0.86	3.36	4.08	4.41
Aug 08	2.53	1.83	2.21	5.94	5.96	**Aug 08**	3.13	3.58	3.79	5.22	4.36
Sep 08	2.62	1.79	2.13	4.50	5.96	**Sep 08**	2.91	3.43	3.53	2.92	3.25

Adequate biological control was maintained at both Fort Huachuca sites (Table 6). Water in both cooling towers showed occasional high counts of bacteria over the course of the DEM/VAL period. However, these spikes in the bacteria counts are a normal occurrence in any evaporative cooling system. No biocides were used at the technology demonstration site.

Table 6. Fort Huachuca – bio-fouling data (cfu/ml).

Fort Huachuca
Biofouling Data (cfu / ml)

Month	South Central Plant - Zeta Treated	North Central Plant - Chemicals
Jul 07	1.E+04	0.E+00
Aug 07	1.E+05	0.E+00
Sep 07	1.E+04	1.E+05
Oct 07	1.E+04	0.E+00
Nov 07	1.E+04	1.E+03
Dec 07	0.E+00	0.E+00
Jan 08	0.E+00	1.E+06
Feb 08	0.E+00	1.E+03
Mar 08	0.E+00	0.E+00
Apr 08	0.E+00	0.E+00
May 08	0.E+00	1.E+04
Jun 08	0.E+00	0.E+00
Jul 08	1.E+03	1.E+03
Aug 08	1.E+04	1.E+05
Sep 08	1.E+06	ND

Data from the corrosion probes (Table 7, Figure 11, and Figure 12) remained relatively steady throughout the DEM/VAL period. The slope in the curve generated by the corrosion probe and transmitter was used to calculate the corrosion rate over a period of time. With an exception at the chemically treated site, which showed an apparent increase in the slope between November 2007 and January 2008, the slope at both sites remained practically flat.

Results from the corrosion coupons, removed on a quarterly basis, corroborated the observations from the electronic corrosion probe and showed that both sites were able to maintain corrosion levels well within the targets set during the DEM/VAL (Table 8).

Water samples from the chemically treated system, taken between May and July of 2008 showed high levels of iron and copper in the water (Table 4). Normally, this would have been a matter of concern with respect to potential corrosion. However, the data generated by the corrosion probe (Table 7) indicated no increase in the corrosion rate in the system. This was further confirmed by the results from the corrosion coupons for that same period.

Table 7. Fort Huachuca – Calculated corrosion rate from corrosion probes.

Fort Huachuca
Calculated Corrosion Rate from Corrosion Probes

Location	Δ Probe Reading (mA)	Δ Time (Days Exposed)	Corrosion (mpy)
South Central Plant - Zeta Treated	0.20	441	0.103
North Central Plant - Chemically Treated	1.40	397	0.804

Table 8. Fort Huachuca – Corrosion data (mpy).

Fort Huachuca
Corrosion Data (mpy)

	South Central Plant - Zeta Treated		**North Central Plant - Chemicals**	
	Mild-Steel Coupon	**Copper Coupon**	**Mild-Steel Coupon**	**Copper Coupon**
Target -	< 5 mpy	< 1 mpy	< 5 mpy	< 1 mpy
Quarter:				
Q1	0.0901	0.1525	0.232	0.0746
Q2	0.1521	0.228	0.1745	0.0876
Q3	0.2024	0.1113	0.226	0.115
Q4	0.1365	0.1627	0.164	0.1705
Average	**0.145275**	**0.163625**	**0.199125**	**0.111925**

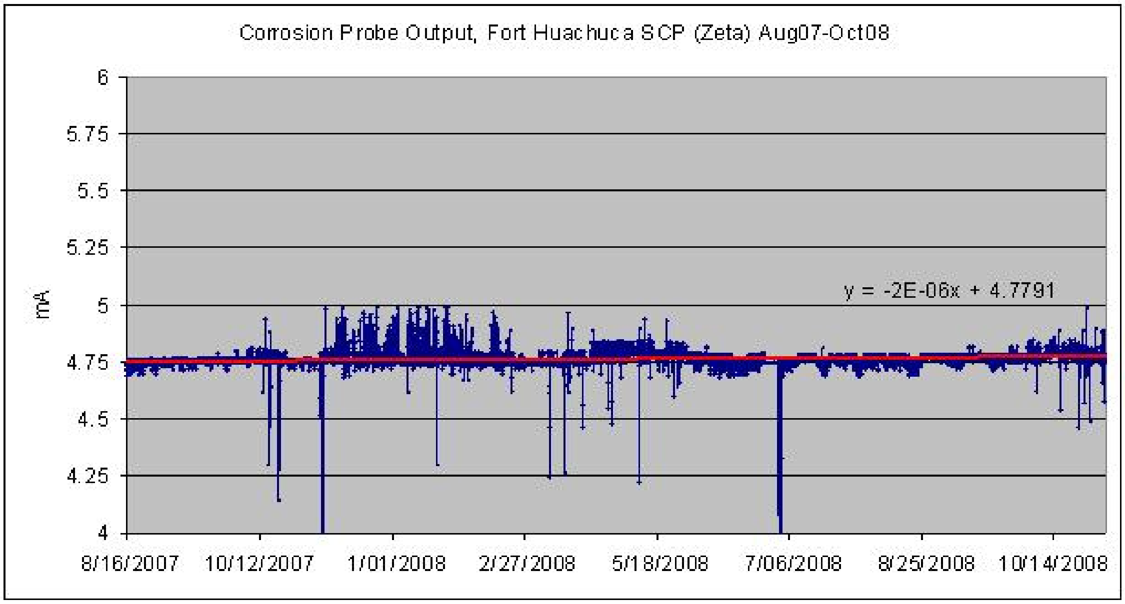

Figure 11. Corrosion probe output, Fort Huachuca SCP (Zeta) Aug 2007 – Oct 2008.

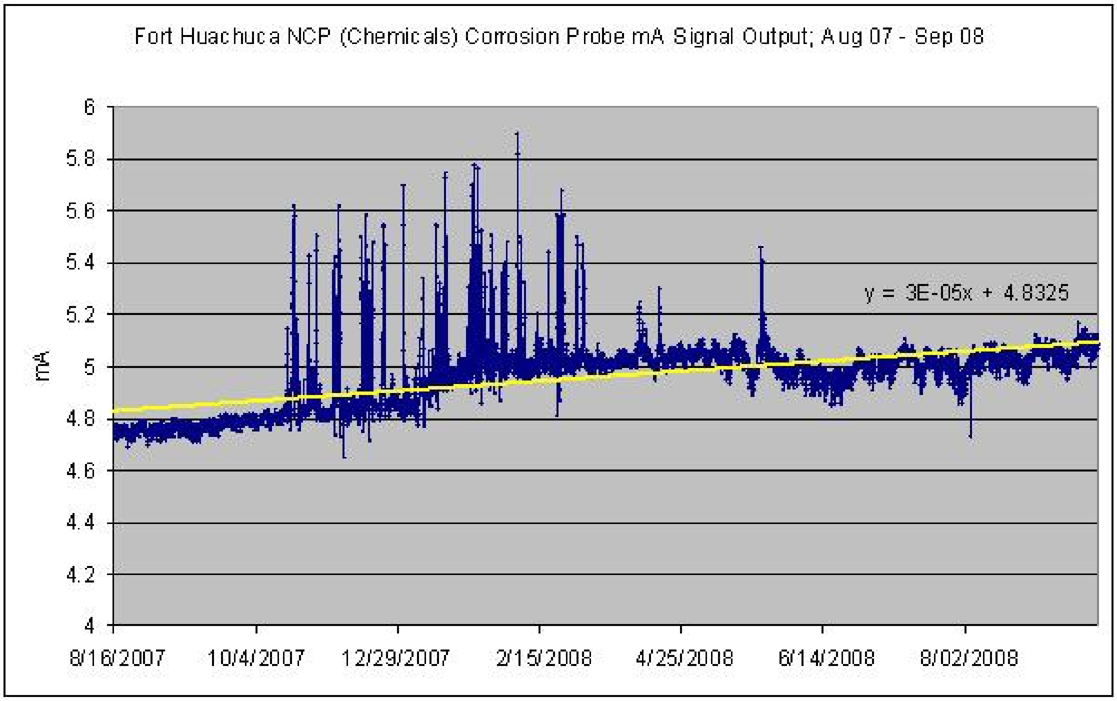

Figure 12. Fort Huachuca (chemicals) corrosion probe mA signal output, Aug 2007–Sep 2008.

6.2 Davis Monthan data results

The MU water for Davis Monthan is sourced from the Tucson, Arizona, municipal supply and showed little seasonal variation in quality (Table 9).

Table 9. Davis Monthan AFB – Make-up water supply analysis.

Davis Monthan
Make-up Water Supply Analysis

Month	Alkalinity Bicarbonate	Alkalinity Carbonate	Alkalinity Total	Conductivity	Hardness (CA)	Hardness (CA / MG)	Chloride	Iron	Copper
Jul 07	130	ND	130	380	110	130	NA	ND	ND
Aug 07	120	ND	120	380	97	120	12	0.049	ND
Sep 07	130	ND	130	400	110	140	8.4	0.054	ND
Oct 07	130	ND	130	400	100	120	8.2	ND	ND
Nov 07	130	ND	130	400	95	120	7.6	0.039	ND
Dec 07	130	ND	130	320	75	94	6	0.039	ND
Jan 08	130	ND	130	310	80	98	4.3	ND	ND
Feb 08	130	ND	130	400	100	130	6.1	ND	ND
Mar 08	120	ND	130	310	77	94	4.8	ND	ND
Apr 08	130	ND	130	310	80	98	4.8	0.036	ND
May 08	130	ND	130	310	67	83	4.6	ND	ND
Jun 08	130	ND	130	300	75	92	4.6	ND	ND
Jul 08	120	ND	120	300	85	100	4.6	ND	ND
Aug 08	120	ND	120	300	77	96	5.8	0.025	ND
Sep 08	120	ND	120	1000 [14]	85	100	6	0.024	ND
Average	**127.3**		**127.3**		**87.5**	**107.7**	**6.3**	**0.018**	**ND**

Data for the cycles of concentration and cooling tower water analysis were further analyzed, and the results for each of the Davis Monthan AFB sites are presented in Tables 10–12. and discussed in the following paragraphs.

Initially, the concentration ratio on both evaporative condensers was set to be controlled by conductivity with a set-point of 1,000 µs, or approximately 3 cycles of concentration. Use of a low-cost conductivity controller in the chemically treated site, historically set to operate on a timer basis as opposed to a conductivity set point, resulted in a wide variation in the conductivity and resulting concentration ratio. The chemically treated tower concentration ratio (as measured by volumetric ratio) ranged from 1.8 cycles to as many as 17 cycles in April of 2008 when, due to a controller malfunction, the BD valve failed to open.

The controller in the Zeta-treated system was set to control cycles of concentration by conductivity with a set-point of 1,000 µs at the beginning of the project. The higher cycles shown by volumetric ratio during the first four months of the project were due to a malfunction of the BD water meter. An old piece of scale that had fallen off the tubes became lodged in the water meter and kept it from spinning freely. In January 2008, a basket strainer was installed in front of the water meter to prevent a recurrence of this problem, and the concentration ratio control was switched to six cycles by volumetric ratio control.

These two sites showed a higher variation between the cycles of concentration, based on chemical analysis and cycles based on volumetric ratio, because of the small volume of water in the basin of these evaporative condensers. The small volume, and the time of the day with respect to when the unit performed its last BD, had a significant impact on the composition of the water in the basin.

Table 10. Davis Monthan AFB Zeta demonstration site (Fitness Center Building 2301) – Cooling tower water analysis.

Davis Monthan
Zeta Demonstration Site (Fitness Center Building 2301) -
Cooling Tower Water Analysis

Month	Alkalinity Bicarbonate	Alkalinity Carbonate	Alkalinity Total	Conductivity	Hardness (CA)	Hardness (CA / MG)	Chloride	Iron	Copper
Jul 07	230	130	360	870	270	340	NA	0.024	0.052
Aug 07	250	200	450	1300	320	420	44	ND	ND
Sep 07	140	100	240	630	190	240	15	ND	ND
Oct 07	150	72	270	620	180	230	12	ND	ND
Nov 07	130	76	210	590	140	180	12	ND	ND
Dec 07	140	ND	140	340	77	99	5.5	ND	ND
Jan 08	Sampling or labeling error resulted in no data for make-up water samples.								
Feb 08	170	130	300	840	230	290	16	ND	ND
Mar 08	200	100	300	670	150	200	13	ND	ND
Apr 08	230	140	3701	960	140	200	25	0.006	0.0006
May 08	180	130	310	780	100	150	20	ND	ND
Jun 08	230	140	380	1100	87	170	32	ND	ND
Jul 08	230	120	350	1200	62	160	31	0	0
Aug 08	150	96	240	710	67	120	21	ND	ND
Sep 08	130	80	210	610	62	110	16	ND	ND

Table 11. Davis Monthan AFB chemical treatment control site (Dormitory Building 3750) – Cooling tower water analysis.

Davis Monthan
Chemical Treatment Control Site (Dormitory Building 3750) -
Cooling Tower Water Analysis

Month	Alkalinity Bicarbonate	Alkalinity Carbonate	Alkalinity Total	Conductivity	Hardness (CA)	Hardness (CA / MG)	Chloride	Iron	Copper
Jul 07	170	ND	170	520	150	190	10	2.9	0.045
Aug 07	250	130	380	970	270	350	35	0.29	ND
Sep 07	340	ND	340	1100	270	360	39	0.26	0.31
Oct 07	240	120	360	960	270	350	20	0.41	ND
Nov 07	160	60	220	680	170	220	14	0.67	ND
Dec 07	160	ND	160	390	87	110	6.6	0.12	ND
Jan 08	190	40	230	520	150	190	8.5	0.36	ND
Feb 08	180	60	240	620	170	220	11	0.27	ND
Mar 08	220	88	310	680	200	250	12	ND	ND
Apr 08	290	150	440	1300	160	220	97	2.3	ND
May 08	200	100	300	690	ND	ND	13	ND	ND
Jun 08	200	120	320	670	75	120	12	0.5	ND
Jul 08	120	40	160	370	160	190	6.4	4.4	0.043
Aug 08	240	140	380	880	240	300	19	0.36	ND
Sep 08	260	140	390	850	280	340	15	0.54	ND

Table 12. Davis Monthan AFB – Cycles of concentration data.

Davis Monthan
Cycles of Concentration Data

	Fitness Center - Zeta Treated					Dormitories - Chemically Treated				
Month	**Conductivity**	**Hardness**	**Alkalinity**	**Chlorides**	**by Volume**	**Month**	**Conductivity**	**Hardness**	**Alkalinity**	**Chlorides**	**by Volume**
Jul 07	2.29	2.62	2.77	-	-	**Jul 07**	1.30	1.36	1.21	1.47	-
Aug 07	3.42	3.50	3.75	3.67	3.90	**Aug 07**	2.55	2.93	3.17	2.92	4.30
Sep 07	1.58	1.71	1.85	1.79	4.30	**Sep 07**	2.75	2.57	2.62	4.64	3.84
Oct 07	1.55	1.92	2.08	1.46	4.80	**Oct 07**	2.40	2.93	2.77	2.44	4.58
Nov 07	1.48	1.50	1.62	1.58	4.90	**Nov 07**	1.70	1.83	1.69	1.84	3.63
Dec 07	1.06	1.05	1.08	0.92	NA	**Dec 07**	1.22	1.17	1.23	1.10	NA
Jan 08	ND	ND	ND	ND	NA	**Jan 08**	1.63	1.90	1.77	1.89	NA
Feb 08	2.10	2.23	2.30	2.62	6.70	**Feb 08**	1.55	1.69	1.84	1.80	2.10
Mar 08	2.16	2.12	2.30	2.70	5.70	**Mar 08**	2.19	2.65	2.38	2.50	2.80
Apr 08	3.09	2.04	2.84	5.20	6.58	**Apr 08**	4.19	2.24	3.38	20.20	17.50
May 08	2.52	1.81	2.38	4.35	6.37	**May 08**	2.23	0.00	2.31	2.83	1.80
Jun 08	3.67	1.85	2.92	6.96	6.01	**Jun 08**	2.23	1.30	2.46	2.61	3.80
Jul 08	4.00	1.60	2.92	6.74	6.20	**Jul 08**	1.23	1.90	1.33	1.39	3.67
Aug 08	2.37	1.25	2.00	3.62	6.13	**Aug 08**	2.93	3.13	3.17	3.28	3.40
Sep 08 [15]	0.61	1.10	1.75	2.67	5.76	**Sep 08** [15]	0.85	3.40	3.25	2.50	3.70

The technology demonstration site (Fitness Center) was visually evaluated for scale control. “Before” photographs of the tubes show the mechanically cleaned sections of tubes (Figure 13 and Figure 14) free from scale deposits. The same sections of tube were photographed “after” during the inspection in September 2008 (Figure 15 and Figure 16), documenting that no new scale formation had taken place.

Figure 13. Mechanically cleaned section of upper tubes on the evaporative condenser at Zeta demonstration site (Davis Monthan AFB Fitness Center, July 2007).

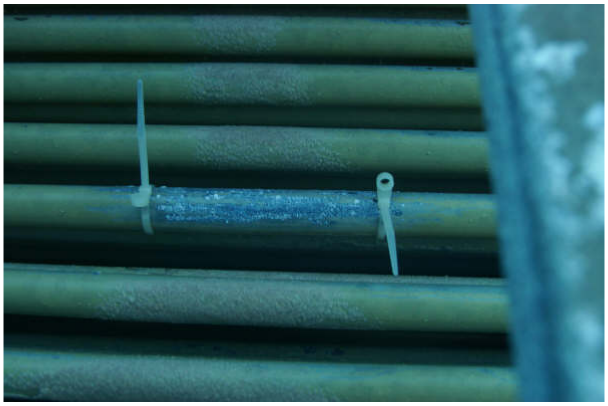

Figure 14. Second area of mechanically cleaned section of upper tubes on the evaporative condenser at Zeta demonstration site (Davis Monthan AFB Fitness Center, July 2007).

Figure 15. "After" photo of clean section of upper tube of evaporative condenser at Zeta demonstration site (Davis Monthan AFB Fitness Center, September 2008).

Figure 16. "After" photo of second clean section of upper tube of evaporative condenser at Zeta demonstration site (Davis Monthan AFB Fitness Center, September 2008).

Biological control was maintained at both sites (Table 13). Both evaporative condensers showed occasional high counts of bacteria in the water over the course of the DEM/VAL period.

Table 13. Davis Monthan AFB – Biofouling Data (cfu / ml).

Davis Monthan
Biofouling Data (cfu / ml)

Month	Fitness Center - Zeta Treated	Dormitories - Chemically Treated
Jul 07	0	0
Aug 07	0	0
Sep 07	0	0
Oct 07	0	0
Nov 07	0	0
Dec 07	0	0
Jan 08	0	0
Feb 08	0	1.E+03
Mar 08	0	0
Apr 08	0	1.E+02
May 08	0	1.E+03
Jun 08	0	0
Jul 08	0	0
Aug 08	1.E+06	1.E+04
Sep 08	1.E+02	1.E+04

Data from the corrosion probes (Table 14, Figure 17, and Figure 18) remained relatively steady throughout the DEM/VAL period. The slope in the curve generated by the corrosion probe and transmitter is used to calculate the corrosion rate over a period of time. As illustrated by the graphs, the slope at both sites remained practically flat. The corrosion coupon analyses were well within target rates (Table 15).

Table 14. Davis Monthan AFB – Calculated corrosion rate from corrosion probes.

Davis Monthan
Calculated Corrosion Rate from Corrosion Probes

Location	Δ Probe Reading (mA)	Δ Time (Days Exposed)	Corrosion (mpy)
Fitness Center - Zeta Treated	0.27	439	0.140
Dormitories - Chemically Treated	0.08	397	0.055

Table 15. Davis Monthan AFB – Corrosion data (mpy).

	Fitness Center - Zeta Treated	Dormitories - Chemically Treated	
	Galvanized Coupon	Stainless Coupon	**Copper Coupon**
Target:	<5 mpy	<1 mpy	<1 mpy
Quarter 1	2.7418	0.308	0.2076
Quarter 2	1.732	0.0051	0.2688
Quarter 3	0.2543	0.0051	0.0261
Quarter 4	2.3949	0.0423	0.1913
Average	1.78075	0.090125	0.17345

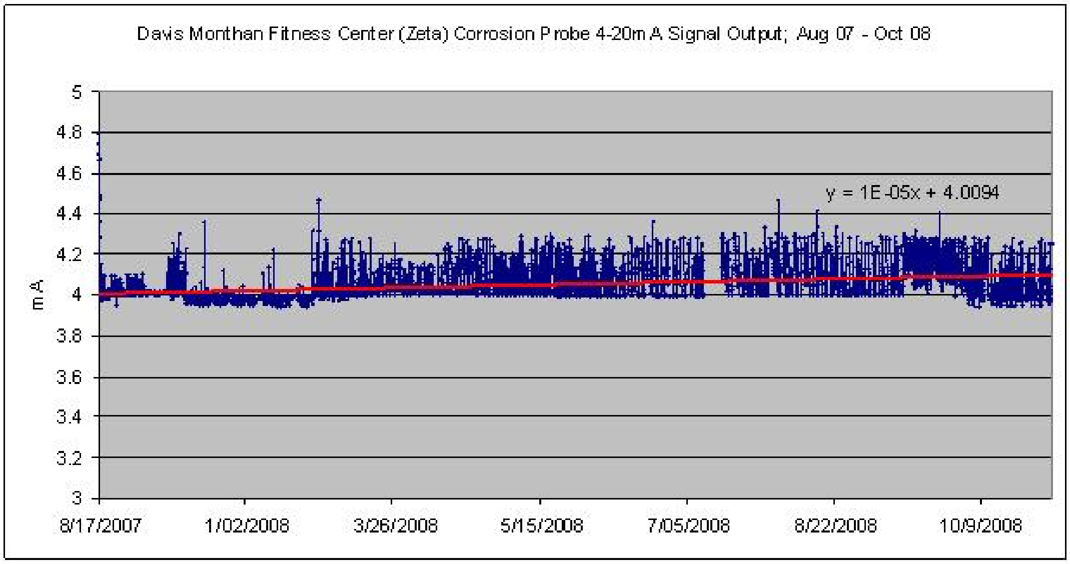

Figure 17. Davis Monthan AFB Fitness Center (Zeta) corrosion probe 4-20mA signal output (Aug 2007–Oct 2008).

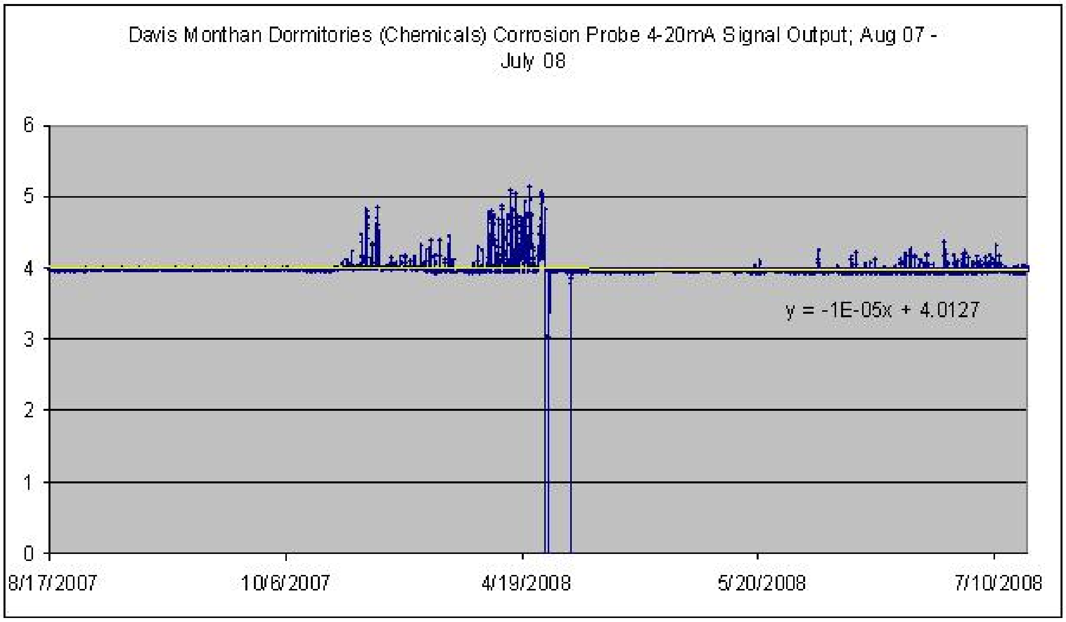

Figure 18. Davis Monthan AFB Dormitories (chemicals) corrosion probe 4-20mA signal output (Aug 2007–July 2008).

6.3 Water and energy data results

Table 16 shows the total amount of water, in gallons, metered at each location on 17 September 2008, representing a period of 14 months. Electrical usage is nominal for both the capacitor-based technology and for the chemical feed pumps (Table 17).

Table 16. Make-up and blow-down total metered usage as of September 17, 2008.

Fort Huachuca (Zeta)		Fort Huachuca (Chemicals)	
Make Up (gal)	4,879,600	Make Up (gal)	6,467,500
Blow Down (gal)	773,000	Blow Down (gal)	1,494,200
Concentration Ratio	6.31	Concentration Ratio	4.33
Davis Monthan (Zeta)		**Davis Monthan (Chemicals)**	
Make Up (gal)	907,000	Make Up (gal)	672,100
Blow Down (gal)	16,675[13]	Blow Down (gal)	245,600
Concentration Ratio	5.61	Concentration Ratio	2.74

Table 17. Electrical usage for technology demonstration equipment and chemical feed pumps.

	DM-Zeta	DM-Chemicals	FH-Zeta	FH-Chemicals
Average Amps	0.275	0.136	0.276	0.0897
Average Watts	18.2	7.03	18.2	5.3
Total kW-hr	176.25	55.50	114.26	57.75
Days	375	375	375	375
Average kWh/day	0.47	0.148	0.305	0.154
Average Daily Cost [14]	$0.03	$0.01	$0.21	$0.01

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[13] Due to a meter blockage early in the DEM/VAL, this reading is much lower than what the actual reading should have been. The figure used for the Davis Monthan Zeta site is a calculation based on the average concentration ratio of 5.61 under which the condenser operated July 2007–September 2008.

[14] Commercial rate of $0.071/kWh as published in Tucson Electric Power's GS-10 General Service published rates (http://www.tucsonelectric.com/Docs/GS-10.pdf)

7 Discussion of the Results

7.1 Scale, corrosion, bacteria and biofilm control

The electronic capacitor-based technology (Zeta) consistently demonstrated successful treatment of the cooling water for scale, corrosion, and bacteria control, without the use of any chemicals despite operation at high cycles of concentration. The chemical treatment programs also delivered fully acceptable results.

The data illustrated that corrosion control levels achieved by the application of the capacitor-based technology can be explained by means of simple chemistry of the water and metals. Operating the evaporative cooling systems at conditions under which there is no corrosion potential successfully eliminated the need for chemical corrosion inhibitors.

Biological populations were well controlled to levels below the established target of $1x10^4$ cfu/ml at both the Zeta-treated and the chemical-treated sites at Davis Monthan AFB. It is important to note that isolated data spikes can occur with a direct correlation to hot and humid summer weather.

Because of larger volumes of water in the Fort Huachuca cooling systems, coupled with the highly cyclic daily operations, the colony counts showed higher variations (as expected). Both the South Central Plant (Zeta) and the North Central Plant (chemicals) maintained bacteria counts within the target levels of $1x10^4$ cfu/ml, and each site reported samples above the targeted levels (Zeta-treated site in August 2007, and chemical-treated site in September 2007 and January 2008). The overall biological control, however, is best evaluated by looking at trends rather than at single datum points. No corrective action was taken, and as anticipated, the bacteria counts at both locations returned to normal. The sampling that occurred during the final visit in October 2008 showed acceptable levels for bacteria counts at both towers.

7.2 Water conservation estimates

The second objective of the DEM/VAL was to demonstrate that the technology could deliver increased water conservation without having a corresponding negative effect in scale, corrosion and biofouling control. Given that the evaporation rate in an evaporative cooling system cannot be controlled, the only possible way to achieve significant reductions in water use is by reducing the amount of BD water, which in turn reduces the amount of MU water required.

The directive set forth by Executive Order 13423 calls for reducing water consumption relative to the facility's baseline by a rate of 2% annually, or by a total of 16% by the end of fiscal year 2015. The water requirements for any given facility's evaporative cooling equipment are not the facility's complete water requirements, but they do represent a significant portion of its overall water usage. If the cooling system water has been chemically treated, it is potentially rendered unusable for other purposes, such as irrigation water or building gray water. As new or existing federal facilities seek LEED[15] or other certification for green building practices, strategies will be sought for water conservation, including gray water re-use.

In the case of Fort Huachuca, water conservation is, and will remain, an objective of critical importance. Fort Huachuca is located on the edge of the San Pedro River National Conservation Area, one of the most important riparian areas in the United States. Lowered water tables threaten the perennial existence of this desert river, giving priority to all efforts to conserve water and halt ground water depletion.

It is important to note that side-by-side comparison cannot be made between the amounts of water used by different locations, even at the same installation. This is due to the fact that, in spite of each installation's systems being similar in size and capacity, they were not similar in operating conditions (load factor and run hours). This was most clearly seen at Davis Monthan AFB, where the Zeta-treated system used approximately twice the amount of water compared to the chemical-treated system, in spite of operating at twice the concentration ratio. This was due to greatly differing operational loads and run factors. The only true way to evaluate the water

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[15] Leadership in Energy and Environmental Design (LEED) Green Building Rating System™ is a rating and certification system developed by The U.S. Green Building Council, a 501 (c) (3) non-profit organization.

conservation derived from increasing cycles of concentration would be to compare two identical systems operating at the same load conditions for the same number of hours, but at different concentration ratios. There were no water meters installed at any of the facilities prior to the project, so for the purposes of this study, water savings estimates must be calculated mathematically.

7.2.1 Fort Huachuca

Water savings in the Fort Huachuca South Central Plant (Zeta) were calculated by taking the total metered volume of MU used during the enhanced water conservation demonstration period (January–September 2008) and adjusting to estimate annual use. In January 2008, the controller was adjusted to produce a cooling tower cycle of concentration at 6 (by volumetric ratio). Table 18 shows the water meter readings on the Zeta-treated system from January 2008 and September 2008.

Table 18: Fort Huachuca, South Central Plant (Zeta) - total metered water usage.

SCP Make Up Meter Readings		SCP Blow Down Meter Readings	
Jan 15, 2008	1,989,900	Jan 15, 2008	324,500
Sep 17, 2008	4,879,600	Sep 17, 2008	773,000
Volume Metered	2,889,700	Volume Metered	448,500

During the 8-month period of enhanced water conservation demonstration, the MU water meter at the South Central Plant recorded a total usage of 2,889,700 gallons (an average of 361,213 gal/month); the BD water meter recorded 448,500 gallons discharged. Therefore, the tower at the South Central Plant operated at an average of 6.44 cycles of concentration during that period of time:

$$2{,}889{,}700 \text{ MU} / 448{,}500 \text{ BD} = 6.44 \text{ cycles}$$

If the tower had operated at 3 cycles of concentration (as it had been operated traditionally) the estimated additional monthly MU water volume is adjusted upward by 21% (the percentage increase in water use, going from 6.44 cycles to 3 cycles). The following calculation shows that volume increase.

361,213 gal per month · 1.21 = 437,067 gal per month (at 3 cycles)

The annual estimate for gallons of water conserved by operating at 6.44 cycles (as opposed to 3 cycles) is calculated below:

437,067 gal – 361,213 gal = 75,854 gal per month

75,854 gal/month · 12 months = 910,248 gal per yr. estimated water savings

Over the 8-year period within which the Executive Order requirements are to be met, this represents a total estimated water savings of 7,281,984 gal. The contribution toward the overall water conservation objective for facilities is greater in the initial years than the 2% annual reduction in water use that is the target. Therefore, facilities may be able to employ the capacitor-based technology to reach the total water use reduction target (16% by 2015) on an accelerated schedule.

Estimated water cost savings may also be calculated — savings that could offset the overall costs of the water treatment program. At the published rate of $0.2418/100 gal[16] for Fort Huachuca, this would be a total water cost savings of $17,607 for fiscal years 2008–2015, assuming concentration ratios remained at 6.44 cycles.

For BD water reduction, the same volume of water (910,248 gal/yr) was conserved, and calculation of the dollar savings in reduced sewer fees could be calculated. The more important consideration would be to calculate the additional water and cost savings available if the BD could be substituted for another water requirement that would otherwise have used fresh, potable water.

7.2.2 Davis Monthan AFB

At the Davis Monthan Fitness Center (Zeta), the same water conservation analysis can be made. Table 19 shows the MU and BD total metered water usage for the 8-month period demonstrating water conservation. The total volume of MU water metered was 431,500 gallons and the BD water metered was 66,670 gallons, representing an average of 6.47 cycles of concentration, as expressed in this equation:

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[16] Arizona Water Company, General Service Tariffs: $0.2418/100 gal for gal in excess of 25,000. http://www.azwater.com/wg-162.pdf

431,500 gal. MU / 66,670 gal. BD = 6.47 cycles of concentration

Table 19: Davis Monthan AFB, Fitness Center (Zeta) – total metered water usage.

DM Fitness Center Make Up Meter		DM Fitness Center Blow Down Meter	
Jan 15, 2008	475,500	Jan 15, 2008	12,030
Sep 17, 2008	907,000	Sep 17, 2008	78,700
Volume Metered	431,500	Volume Metered	66,670

At 6.47 cycles of concentration, 431,500 gal/8 months = 53,938 gal/month of water usage. The percentage increase in water use going from 6.47 cycles to 3 cycles is 21.14%. The increase in water usage to operate at low cycles would be expressed as follows:

53,938 gal per month · 1.2114 = 65,340 gal/month (at 3 cycles)

The per-month MU water savings and annual MU water savings would be expressed by the following two equations:

65,340 gal. per month – 53,938 gal. per month = 11,402 gal/month savings

11,402 gal per month saved · 12 mo. = 136,824 gal. savings per year

Thus, the total water volume savings for the 8-year period would multiply to 1,094,592 gal (1,463 ccf). The published cost of water for Davis Monthan AFB at the time of the study was $1.93/ccf[17]:

1,463 ccf · $1.93 per ccf = $2,824.00 total water cost savings

Again, the reduction in BD volume would reduce sewer fees and would make the BD available for other gray water uses (e.g., irrigation) because it would be free of added water treatment chemicals.

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[17] Tucson, Arizona: 1.93/ccf (hundred cubic feet; 1ccf = 748 gal). http://www.ci.tucson.az.us/water/rates.htm

7.3 Energy consumption

While energy consumption comparisons were made between the energy to power a chemical feed pump and the energy to power the capacitor-based technology (both negligible), the significant energy savings when operating an evaporative cooling system are achieved by keeping the heat transfer surfaces as clean as possible.

One characteristic of the technology is that as the biofilms are loosened, any associated scale buildup is likely to lose its grip on the surface to which it is adhered. This was observed in the cooling towers of both Zeta-treated systems, where large sheets of scale came loose from the cooling tower basins, fill, and the tube bundles of the evaporative condenser, thus exposing the clean surfaces beneath. Scale in the cooling tower fill lost its grip and fell into the basin. It was important to monitor this action and remove the debris to avoid re-entrainment into the system circulation.

While not intended as a scale removal technology, if heat transfer surfaces are clean under the influence of the electrostatic field, scale is unlikely to form. Because the technology operates effectively at high concentration ratios, conditions for corrosion are avoided.

7.4 Wireless remote monitoring and control

Perhaps the most difficult objective of the study was to complete the wireless remote monitoring and control system. The more limited capabilities of existing controllers, coupled with site-specific issues related to communications security, made the task both daunting and time-consuming.

Special recognition is due Lakewood Instruments for working with Zeta Corporation to develop the necessary software that allowed the controllers to interface with a wireless protocol. This process took many months, but when finally de-bugged, allowed many parameters to be reliably monitored and controlled from virtually anywhere in the world that has access to the Internet. The ability to remotely monitor and control system operation during the latter phases of the study proved invaluable in reducing on-site monitoring and supervision time, and alerting study participants to acute events that could have affected operating conditions and interrupted data collection.

With the capacitor-based system, demonstration of the importance of volumetric control of concentration ratios, coupled with the development of the remote monitoring controllers, established a reliable method for ensuring a successful water conservation program.

8 Conclusion

The Zeta Rod technology evaluated under this CRADA met every objective of the comparison effort. The abundant data collected confirms that the technology was as effective as the chemical treatment programs in protecting the cooling systems from scale, biofouling, and corrosion.

Effective operation of evaporative cooling systems without chemical additives of any kind has been demonstrated. Additionally, demonstrated water savings from using capacitor-based technology shows great potential for contributing to the water conservation goals of federal facilities.

The development of the wireless remote monitoring system was useful during this study and also would be a useful tool for facility personnel who wish to enhance the monitoring capabilities of their water treatment programs.

In summary, application of this technology would allow the DoD to (1) reduce chemical usage, exposure, and disposal expenses; (2) conserve water and energy; (3) facilitate water re-use; and (4) meet DoD goals for conservation of resources.

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Appendix A

Water samples were collected on a monthly basis and sent to Turner Laboratories in Tucson, Arizona, for analyses. The samples collected were from each one of the four locations, and from the MU water at each one of the two bases. The samples were analyzed for the following:

- **ICP Total Metals: Calcium, Copper, Iron, Magnesium, Zinc**. EPA Method 200.7, Rev. 4.4, "Methods for the Determination of Metals in Environmental Samples - Supplement 1," EPA 600/R-94/111, EMSL, Cincinnati, Ohio, May 1994.
- **Anions by Ion Chromatography**: **Chloride.** EPA Method 300.0, Revision 2.1, "Methods for the Determination of Inorganic Substances in Environmental Samples," EPA-600/R-93-100, August 1993.
- **Alkalinity (Bicarbonate as CaCO3, Carbonate as CaCO3, Hydroxide as CaCO3, Total as CaCO3)**. Standard Method 2320 B, "Standard Methods for the Examination of Water and Wastewater," 20th Edition, APHA – AWWA – WPCF, Washington, D.C., 1998
- **Conductivity.** Standard Method 2510 B, "Standard Methods for the Examination of Water and Wastewater," 20th Edition, APHA –AWWA – WPCF, Washington, D.C., 1998.
- **Hardness (Calcium as CaCO3, Calcium/Magnesium as CaCO3).** Standard Method 2340 B, "Standard Methods for the Examination of Water and Wastewater," 20th Edition, APHA – AWWA – WPCF, Washington, D.C., 1998.

During the monthly visits, dip slides[18] were also collected at all four sites for total bacteria, yeast, and mold analyses. The slides were taken to Turner Labs where they were incubated at the proper temperature and for the proper period of time per the manufacturer's recommendations.

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[18] Dip Slides Model 2620810 Paddle Tester, Total Aerobic Bacteria/Yeast & Mold, by HACH Co. (www.hach.com)

Appendix B

Electrical resistance (ER) corrosion probes and transmitters

Probes utilized

ER327E0031137500. Adjustable Length E/R probe with 40-mil, epoxy sealed, wire loop element in carbon steel/copper on ¾-in. MNPT nylon fitting.

Transmitters

IN2500E. 4-20mA Single Channel E/R Transmitter Instrument.

Manufacturer

Metal Samples Co. Inc.
Post Office Box 8
152 Metal Samples Road
Mumford, Alabama 36268
Telephone: 256-358-4202

Introduction[19]

The electrical resistance (ER) technique is an "on-line" method of monitoring the rate of corrosion and the extent of total metal loss for metallic equipment or structures. The ER technique measures the effects of both the electrochemical and the mechanical components of corrosion, such as erosion or cavitation. It is the only on-line, instrumented technique applicable to virtually all types of corrosive environments. Although universally applicable, the ER method is uniquely suited to corrosive environments having either poor or non-continuous electrolytes such as vapors, gases, soils, "wet" hydro-carbons, and non-aqueous liquids. Other examples of situations where the ER approach can be useful include:

- oil/gas production and transmission systems

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[19] Information on introduction and principles of operation of the ER Probes was obtained from the Metal Samples Web site (http://www.alspi.com/erintro.htm), where the full text can be found.

- refinery/petrochemical process streams
- external surfaces of buried pipelines
- feed-water systems
- flue gas stacks
- architectural structures

An ER monitoring system consists of an instrument connected to a probe and the instrument may be permanently installed to provide continuous information. It also may be portable for gathering periodic data from a number of locations. The probe is equipped with a sensing element that has a composition similar to that of the process equipment of interest.

Principles of operation

The electrical resistance of a metal or alloy element is given by the following formula:

$$R = r \cdot \frac{L}{A}$$

where:

L = Element length
A = Cross sectional area
r = Specific resistance

Reduction (metal loss) in the element's cross section due to corrosion will be accompanied by a proportionate increase in the element's electrical resistance.

Practical measurement is achieved using ER probes equipped with an element that is freely "exposed" to the corrosive fluid, and a "reference" element sealed within the probe body.

Determining the corrosion rate

The following formula is used to determine the corrosion rate occurring at the installed probe:

$$\text{Corrosion Rate (mpy)} = [\Delta \text{ Probe reading (mA)} / 16\text{(mA)}] \cdot [\text{Effective Probe Life (mils)} / \Delta \text{ Time(days)}] \cdot [365 \text{ (days)} / \text{(year)}]$$

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6. AUTHOR(S)
Alfred D. Beitelman, M. Michael Pitts Jr. PhD, Rodrigo F. V. Romo, and Carolyn B. Pitts

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Zeta Corporation
2045 N Forbes Blvd.
Suite 102
Tucson AZ 85745

8. PERFORMING ORGANIZATION REPORT NUMBER

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14. ABSTRACT

The United States Department of Defense (DoD) has a specific legislative mandate to increase its conservation of water and energy. It also is interested in improving the effectiveness of open-loop, cooling water treatment processes at its installations worldwide, for purposes of extending the useful life of evaporative cooling equipment and reducing energy use/costs. A Cooperative Research and Development Agreement (CRADA) was approved to demonstrate that, without using chemical additives, a capacitor-based water treatment system is capable of (1) providing equivalent protection to a chemical treatment program in preventing scale, corrosion, and biofouling; (2) allowing cooling systems to be operated in an enhanced water conservation mode; (3) delivering measurable reductions in water usage over conventional methods; and (4) providing control, monitoring, and wireless data transfer via the Internet. Results documented in the subsequent demonstration and evaluation project showed the technology was able to meet every objective and also was able to deliver a 20% reduction in cooling water use over standard chemical treatment methods. Application of this technology would allow the DoD to (1) reduce chemical usage, exposure, and disposal expenses; (2) conserve water and energy; (3) facilitate water re-use; and (4) meet new goals for conservation of resources.

15. SUBJECT TERMS

water conservation	corrosion control	remote monitoring
cooling systems	HVACR	

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