Dolphin System
Water Treatment Study

Conducted at

MCI

Sacramento Local OPS Facility
11085 Sun Center Drive
Rancho Cordova, CA 95670

<u>Prepared For:</u>
SMUD Customer Advanced Technologies Program

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MCI
Dolphin Non-Chemical Water Treatment System Test

Executive Summary

MCI's Sacramento Local OPS Facility in Rancho Cordova, CA commissioned a test of a non-chemical water treatment system from Clearwater Systems LLC (Dolphin System) on their #4 cooling tower. The results of the test were:

- Significant cleaning of the plate-and-frame heat exchanger.
- Consistently low bacteria levels.
- Good corrosion results.
- Elimination of nearly all chemical treatment. One biocide application was conducted over the six-month test period.

Based on the operational results, the Dolphin pulse-power treatment system is a viable alternative to traditional chemical treatment regiments and provides both operational and environmental advantages.

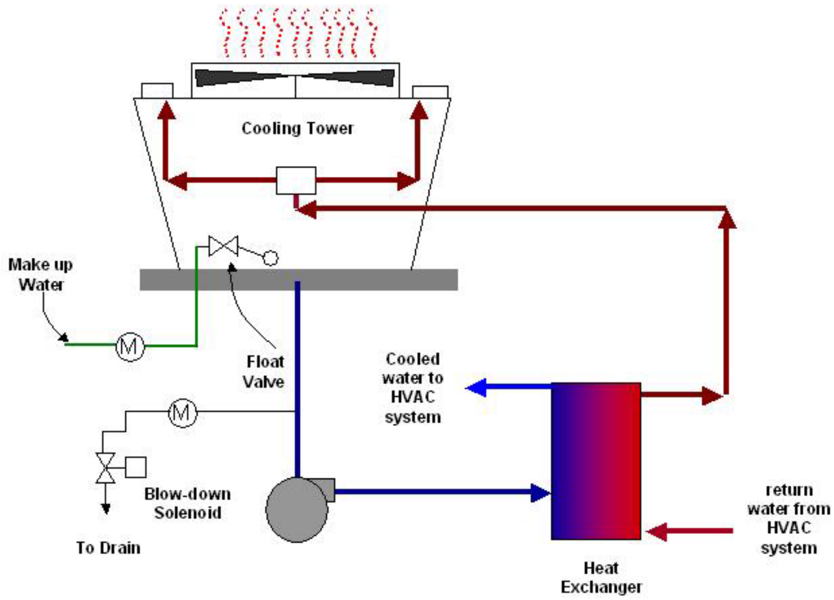
Introduction: In December 2003 MCI contracted with BWI Solutions, Inc., a Sacramento based industrial water treatment and consulting company, to conduct water tests and corrosion coupon samples of a pulsed power water treatment system being tested at MCI's Sacramento Local OPS Facility in Rancho Cordova, CA.

MCI's Sacramento OPS Facility has primary and back up 330-ton cooling towers that cool an HVAC closed loop through a "Superchanger" model UX-A16-HP-139 plate-and-frame heat exchanger. The tower has been chemically treated since installation to control scale, corrosion and biological activity. Under chemical treatment the cooling tower was operated at approximately 2.5 cycles of concentration or "cycles*."

Background: The cooling tower uses ordinary tap water or "city" water, which contains low levels of minerals such as calcium carbonate and silica. As some of the water evaporates in the cooling tower it cools towards the dew point temperature leaving the remaining system water cooler but with increased mineral content, since the minerals do not evaporate and mist drift amounts are negligible. A 330-ton cooling tower at full load evaporates approximately 505 gallons per hour of water causing these minerals to build up in the system water. This mineral build-up can cause scaling so control measures are used to keep the mineral content below potential scaling levels. Both chemical treatment and mechanical control measures, e.g. "blow down" (the draining of some mineral rich water to the sewer that is replaced in the system by fresh water) are used to keep mineral levels in control and prevent scaling. At 2.5 cycles, the tower control system blows down approximately 337 gallons of system water per hour under full load conditions.

* Cycles are the comparison of the system water mineral content to make-up water mineral content and are defined as make-up water volume divided by blow down water volume

A conductivity controller measures and controls the system water conductivity, which is driven by the water's mineral content. Once the controller's conductivity set point is reached, a solenoid valve opens, "blowing down" system water. The drained system water is replaced by fresh water from the float valve in the cooling tower.



MCI purchased a Dolphin Series Pulsed Power Water Treatment System to test its effectiveness in controlling scale, corrosion and biological activity in the cooling tower "open loop" without the use of chemicals. The Dolphin unit was installed on the open loop directly in front of the inlet to the heat exchanger in February 2004.

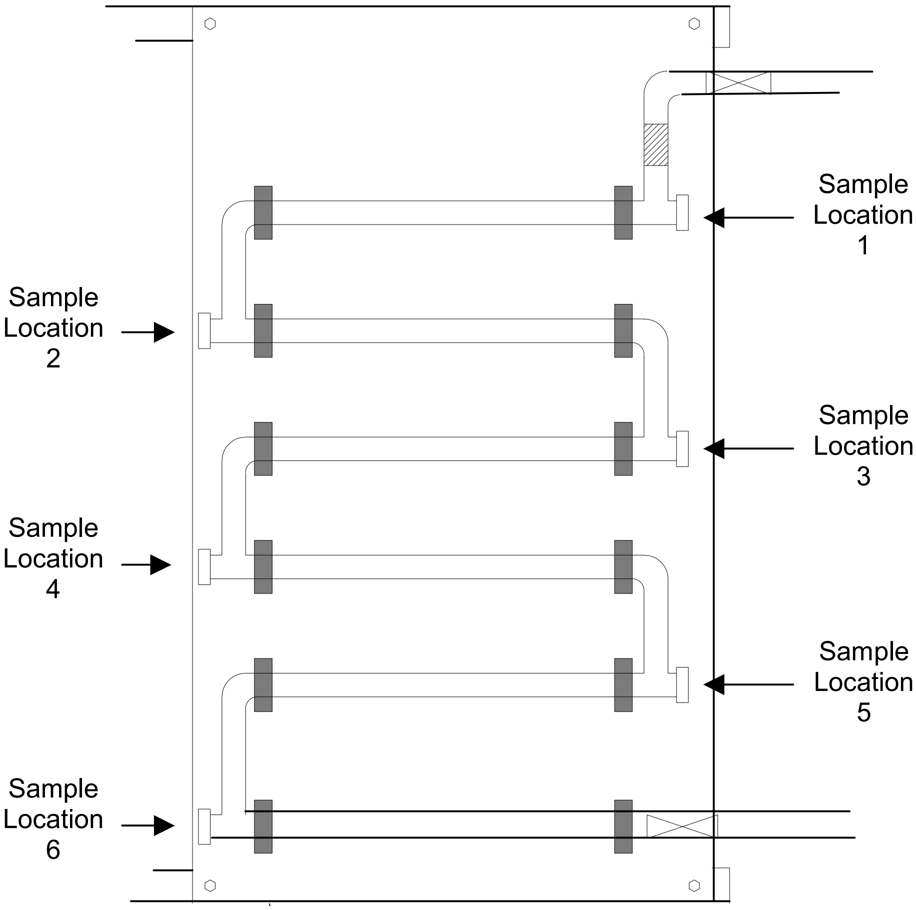
Study Measurement Parameters: The heat exchanger had existing inlet and outlet pressure and temperature gauges on both the open cooling tower loop and the closed cooling loop. The open loop gauges were read monthly by BWI staff and more frequently by the MCI engineering staff. At the start of the test the heat exchanger had a differential pressure of 17 psi.

The cooling tower make-up and blow down lines were equipped with manually read ABB/AMCO C-700 water meters. The purpose of the meters was to accurately determine the cooling tower cycles. The water meters were read monthly by BWI staff and more frequently by the MCI engineering staff.

Conductivity was controlled in the cooling tower using the existing conductivity controller and associated solenoid valve. Conductivity data was measured monthly by BWI staff and more frequently by the MCI engineering staff. Chemical feed was disabled during the test period.

Corrosion Coupon Test: Corrosion coupon tests were conducted in accordance with ASTM D 2688-94, Standard Test Methods for Corrosivity of Water in the Absence of Heat Transfer (Weight Loss Methods), using Test Method A - Coupons. A PVC coupon rack containing six coupon positions was installed in the conductivity controller sample stream of the cooling tower. Flow within the sample stream was regulated to 5 gallons per minute, providing approximately 3.6 ft/sec through the rack. Steel (C1010) and copper (CDA110) alloy coupons were provided and analyzed by Metal Samples Company, Inc. of Munford AL. Since corrosion will be high initially and then fall to a lower, nearly constant rate, two time series were conducted: a short-term (5, 10 and 15-day) and long-term (30, 60 and 90-day) sample interval. The short-term intervals were to determine the rate at which passivity occurs. The long-term intervals were to determine the annual corrosion rate.

MCI Corrosion Coupon Rack Sample Locations and Schedule:



Corrosion Coupon Rack

The following coupon placement and removal schedule was used during the test:

February 10, 2004 – Tuesday

Insert C1010 90-day sample (SN W5762) in location #1
Insert CDA110 90-day sample (SN M4392) in location #2
Insert C1010 10-day sample (SN V7124) in location #3
Insert CDA110 10-day sample (SN M4400) in location #4
Insert C1010 15-day sample (SN V7540) in location #5
Insert CDA110 15-day sample (SN M4401) in location #6

February 20, 2004 – Friday

Pull #3 C1010 10-day sample and insert C1010 5-day sample (SN 5755) in location #3
Pull #4 CDA110 10-day sample and insert CDA110 5-day sample (SN M4393) in location #4

February 25, 2004 – Wednesday

Pull #3 C1010 5-day sample and insert C1010 30-day sample (SN W5760) in location #3
Pull #4 CDA110 5-day sample and insert CDA110 30-day sample (SN M4398) in location #4
Pull #5 C1010 15-day sample and insert C1010 60-day sample (SN W5761) in location #5
Pull #6 CDA110 15-day sample and insert CDA110 60-day sample (SN M4399) in location #6

March 26, 2004 – Friday

Pull #3 C1010 30-day sample
Pull #4 CDA110 30-day sample

April 25, 2004 – Sunday

Pull #5 C1010 60-day sample
Pull #6 CDA110 60-day sample

May 10, 2004 – Monday

Pull #1 C1010 90-day sample
Pull #2 CDA110 90-day sample

Corrosion Coupon Results:

Exposure Period	**Copper Coupon Corrosion Rate (CDA110)**	**Steel Coupon Corrosion Rate (C1010)**
5 days*	1.1055 mils per year	1.0013 mils per year
10 days*	1.1071 mils per year	0.7839 mils per year
15 days*	0.6289 mils per year	0.4061 mils per year

30 days	0.7287 mils per year	1.7858 mils per year**
60 days	0.3924 mils per year	0.4750 mils per year
90 days*	0.4708 mils per year	0.4370 mils per year

* These coupons were placed when there were still some residual water treatment chemicals in the system water (6.5 ppm phosphonate on February 20, 2004). No chemical feed was done once the Pulsed Power Unit was installed but the water was not drained and refilled either, so the original chemicals were lost only to blow down.

** In the 2003 Sacramento City College Rodda North study, there was no residual treatment chemical in the system water when the corrosion coupons were placed and passivation was very slow to reach steady state. The 30-day sample in the Rodda North study was 3.1 mils per year and continued to drop through the 90-day sample, reaching 1.5 mills per year. In comparison, the MCI study showed passivation occurred almost immediately. Therefore, we recommend that corrosion inhibitors be used during the first week of start-up of new Dolphin equipped systems to accelerate passivation.

All corrosion rates were acceptable at less than 2 mils per year. Since the cooling tower had been treated with chemical inhibitors without dumping the tower before the change to the Dolphin System, the passivation rates were nearly immediate (less than 5 days). In prior studies, passivation began to occur between the 15-day and 30-day samples for the pulsed power treated system, which may explain the slight increase in corrosion rates between the 15-day samples and the 30-day samples.

- *Passivation Recommendation:* Passivate new galvanized cooling towers and iron piping systems with chemical treatment for the first 30-days in conjunction with the Dolphin System.
- *Tower Material Recommendation*: Use stainless steel cooling towers, not galvanized, due to the longer life and less potential damage from high pH that can cause "white rust" on today's galvanized surfaces. If stainless towers are used, passivation is not required. The high initial iron corrosion rates seen in prior Dolphin studies do not last long enough to damage the iron piping.

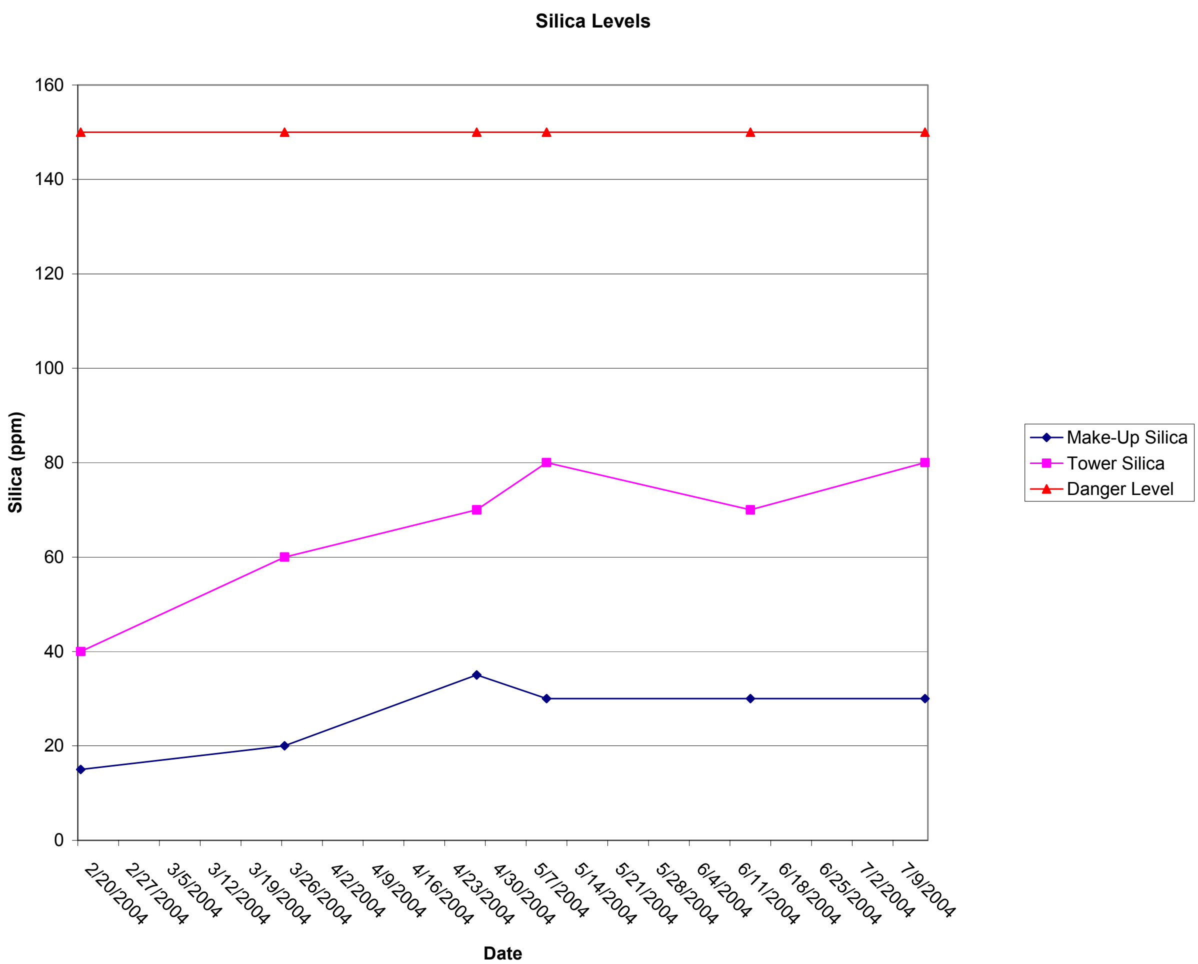
Water Tests: Industrial water tests were conducted monthly from February 2004 through July 2004 by BWI Solutions, Inc. to provide 6 months of data for analysis. Make-up water and tower water samples were taken and analyzed using the following analysis methods:

- Conductivity and pH: Myron L Company, 6P Ultrameter. Conductivity resolution 0.01 microsiemen through the 0-100 microsiemen range, 0.1 microsiemen through the 100-1000 microsiemen range. 0-14 pH measurement with 0.01 pH resolution.
- LaMotte Company 2020 Turbidimeter
- Troy Biological TB-900 Total Bacteria, Yeast and Fungi Dip Slides
- LaMotte Company Single Parameter Tests:
    - Alkalinity 7240-01, 25 ppm/drop
    - Chloride 7172, 10 ppm/drop
    - Hardness 7246, 5 ppm/drop
    - Iron 4447, Visual Color Comparator, 0.5-10 ppm

- Phosphonate 7625-DR, Direct Reading Titrator read to nearest 1 ppm
- Silica 4463, 0.5-10 ppm, 5-100 ppm (diluted, 10 ppm resolution), 50-1000 ppm (diluted, 100 ppm resolution)

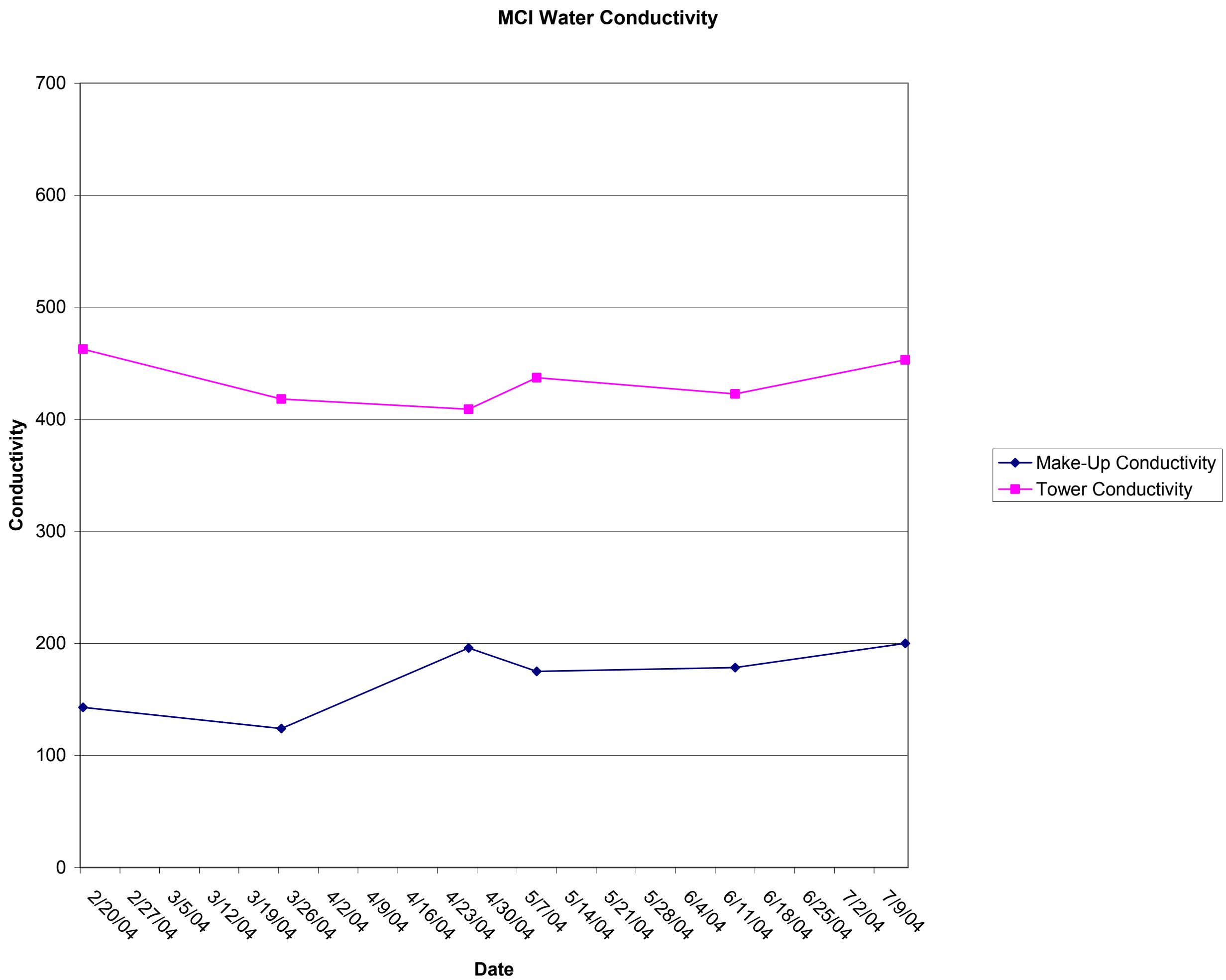
Dip slides were exposed when the water samples were drawn. Other water tests were conducted at BWI Solutions Inc. within 24 hours of the sample being drawn.

Water Test Findings: The make-up water at MCI has significant silica levels (up to 35 ppm). Silica will reach saturation and cause scaling at 180 ppm or more; therefore, the safe operating "cycles" or conductivity setting is constrained by the silica at the MCI facility. Tower conductivity levels were kept the same as under chemical treatment during this test due to the concern of not exceeding silica saturation levels. It is not known if the Dolphin System will control high



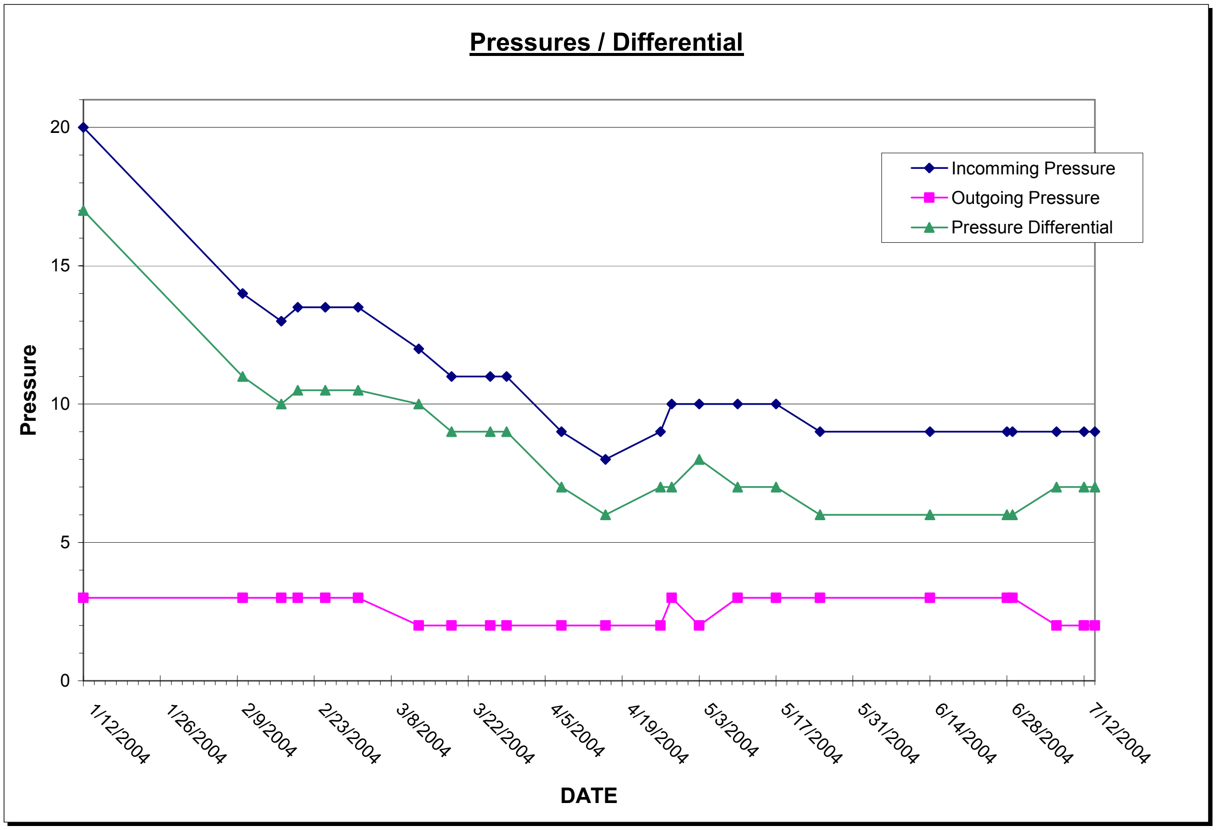
silica levels.

- *Silica Recommendation:* Do not routinely exceed 150-ppm silica in the cooling tower when using the Dolphin system. Test the make-up water silica levels periodically and adjust the conductivity controller set point to keep the product of (tower cycles X make-up water silica level) below 150 ppm. There is room to run the MCI tower at higher levels of conductivity without reaching the 150 ppm silica “danger level.” A conductivity controller set point of 650-700 microsiemen is reasonable.



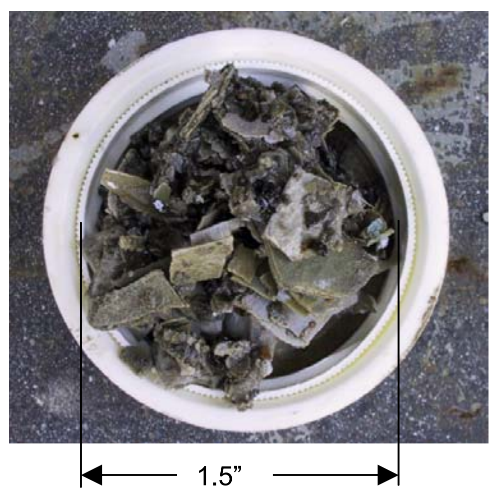
During the test period, the MCI staff, with input from the local Dolphin supplier (Precision Environmental and Power, El Dorado Hills, CA), kept the cooling tower conductivity levels nearly equivalent to levels maintained using chemical treatment because of silica concerns

Operating Results: The result of the Dolphin System operation was <u>significant cleaning</u> of the plate-and-frame heat exchanger from starting differential pressure of 17 psi to 7 psi, <u>a drop of 10 psi.</u>



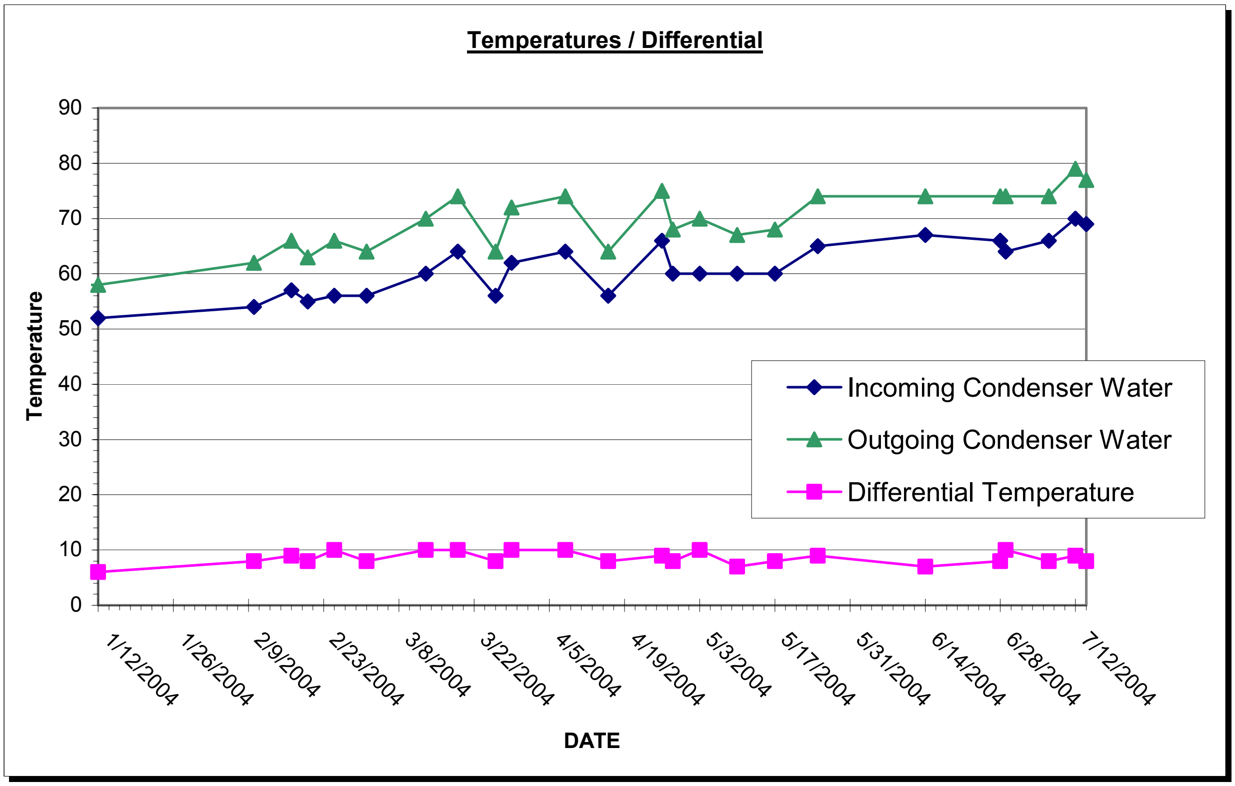
After two months of operation with the Dolphin System, large volumes of old scale began to dislodge. The old scale chips clogged the sample stream and blow down line strainers on April 6, 2004. The scale chips were generally less the ¼" square. The week of June 7, 2004, the MCI engineering staff cleaned the tower and removed the significant amounts of old scale chips that had accumulated in the tower pan. The tower pan was still clean on BWI staff's July 14 visit.

- *Anti-Clogging Recommendation:* To prevent clogging of system blow down strainers and solenoid valves, eliminate the strainer and replace the solenoid valve with a full port motorized ball valve.



Plastic bottle lid containing scale chips removed from the clogged strainer on 4/6/2004

No significant change was seen in the heat exchanger open loop differential temperature over the test period. The lack of increased differential temperature indicates that although the heat exchanger flow rate was restricted at the start of the study by scale, the plate surface area was adequate to remove the required heat load. The closed loop temperature was not monitored during the study.



Bacteria and Biofilms: Dip slide bacterial cultures of the tower water were all well below established control limits. The highest value was 10,000 colony forming units (CFUs) per milliliter (immediately after cleaning the tower). The normal bacteria levels were 1,000 CFUs or less. Yeast and Fungus was not detected on the dip slide cultures.

On March 26, 2004 BWI staff observed a thin, greenish bio-film on the corrosion coupon rack holder and on May 10 the BWI staff observed some algae on the edges of the tower fill. This bio-film is consistent with other Dolphin installations the BWI staff has seen. The MCI staff applied a small amount of oxidizing biocide and cleaned the tower the week of June 7, 2004. As a result, all visible bio-films were removed and had not returned by BWI staff's July 14, 2004 visit.

- *Bio-Film Recommendation:* To control any bio-films that form, manually apply a bio-dispersant (such a Buckman Laboratories BSC 8000) or biocide as needed (typically quarterly). The bio-dispersant will slough off any algae and bio-films so that they will be exposed to the Dolphin electric field in the reaction chamber and then blown down. An oxidizing biocide will kill the algae and bio-films.

Conclusion
The Dolphin water treatment system provided very good results on the three significant water treatment parameters (scale, corrosion and bacteria). The system still requires monitoring of the conductivity control system to unsure proper operation (no clogging, etc.) and periodic cleaning or treatment of any Biofilms that develop.

Monthly Water Test Results

Date	Location	
20-Feb-04	MCI	Result
Make- Up Water		
	Conductivity (µS)	142.9
	pH	7.7
	P-Alkalinity (ppm)	0
	M-Alkalinity (ppm)	50
	T-Alkalinity (ppm)	50
	Hardness (ppm)	42
	Silica (ppm)	15
	Chlorides (ppm)	20
	Iron (ppm)	0
	Turbidity (NTU)	0.35
	Make-Up Water Since 2/17/04 (gal)	6538
	Phosphonate (ppm)	1.5
Cooling Tower		
	Conductivity (µS)	462.6
	pH	8.5
	Phosphonate (ppm)	6.5
	P-Alkalinity (ppm)	10
	M-Alkalinity (ppm)	140
	T-Alkalinity (ppm)	150
	Hardness (ppm)	130
	Silica (ppm)	40
	Chlorides (ppm)	40
	Iron (ppm)	0
	Turbidity (NTU)	0.35
	Blow-Down Water Since 2/17/04 (gal)	2496
	Bacteria	<10,000 CFU/ml
	Fungi/Yeast	None Detected
Cycle Calculations		
Based on Conductivity	3.2	
Hardness	3.1	
Chlorides	2	
Water Meter	2.6	

Monthly Water Test Results

Date	Location	
26-Mar-04	MCI	Result
Make- Up Water		
	Conductivity (µS)	124
	pH	7.8
	P-Alkalinity (ppm)	0
	M-Alkalinity (ppm)	50
	T-Alkalinity (ppm)	50
	Hardness (ppm)	60
	Silica (ppm)	20
	Chlorides (ppm)	20
	Iron (ppm)	0
	Turbidity (NTU)	0.15
	Make-Up Water Since 2/20/04 (gal)	122244
	Phosphonate (ppm)	<1
Cooling Tower		
	Conductivity (µS)	418
	pH	8.4
	Phosphonate (ppm)	2
	P-Alkalinity (ppm)	10
	M-Alkalinity (ppm)	130
	T-Alkalinity (ppm)	140
	Hardness (ppm)	170
	Silica (ppm)	60
	Chlorides (ppm)	40
	Iron (ppm)	0
	Turbidity (NTU)	0.3
	Blow-Down Water Since 2/20/04 (gal)	42666
	Bacteria (CFU/ml)	<1000
	Fungi/Yeast	None Detected
Cycle Calculations		
Based on Conductivity	3.4	
Hardness	2.8	
Chlorides	2	
Water Meter	2.9	

Monthly Water Test Results

Date	Location	
28-Apr-04	MCI	Result
Make- Up Water		
	Conductivity (µS)	196
	pH	7.2
	P-Alkalinity (ppm)	0
	M-Alkalinity (ppm)	100
	T-Alkalinity (ppm)	100
	Hardness (ppm)	90
	Silica (ppm)	35
	Chlorides (ppm)	20
	Iron (ppm)	0
	Turbidity (NTU)	0.9
	Make-Up Water Since 3/26/04 (gal)	131751
	Phosphonate (ppm)	2
Cooling Tower		
	Conductivity (µS)	409
	pH	8.4
	Phosphonate (ppm)	2
	P-Alkalinity (ppm)	25
	M-Alkalinity (ppm)	175
	T-Alkalinity (ppm)	200
	Hardness (ppm)	170
	Silica (ppm)	70
	Chlorides (ppm)	30
	Iron (ppm)	0
	Turbidity (NTU)	0.2
	Blow-Down Water Since 3/26/04 (gal)	41233
	Bacteria (CFU/ml)	1000
	Fungi/Yeast	<1000
Cycle Calculations		
Based on Conductivity	2.1	
Hardness	1.9	
Chlorides	1.5	
Water Meter	3.2	

Monthly Water Test Results

Date	Location	
10-May-04	MCI	Result
Make- Up Water		
	Conductivity (µS)	175
	pH	7.4
	P-Alkalinity (ppm)	0
	M-Alkalinity (ppm)	75
	T-Alkalinity (ppm)	75
	Hardness (ppm)	50
	Silica (ppm)	30
	Chlorides (ppm)	20
	Iron (ppm)	0
	Turbidity (NTU)	0.45
	Make-Up Water Since 4/28/04 (gal)	67437
	Phosphonate (ppm)	3
Cooling Tower		
	Conductivity (µS)	437
	pH	8.2
	Phosphonate (ppm)	4.5
	P-Alkalinity (ppm)	0
	M-Alkalinity (ppm)	200
	T-Alkalinity (ppm)	200
	Hardness (ppm)	170
	Silica (ppm)	80
	Chlorides (ppm)	30
	Iron (ppm)	0
	Turbidity (NTU)	0.25
	Blow-Down Water Since 4/28/04 (gal)	23869
	Bacteria (CFU/ml)	1000
	Fungi/Yeast	None detected
Cycle Calculations		
Based on Conductivity	2.5	
Hardness	3.4	
Chlorides	1.5	
Water Meter	2.8	

Monthly Water Test Results

Date	Location	
14-Jun-04	MCI	Result
Make- Up Water		
	Conductivity (µS)	178.4
	pH	7.7
	P-Alkalinity (ppm)	0
	M-Alkalinity (ppm)	60
	T-Alkalinity (ppm)	60
	Hardness (ppm)	65
	Silica (ppm)	30
	Chlorides (ppm)	20
	Iron (ppm)	0
	Turbidity (NTU)	0.45
	Make-Up Water Since 5/10/04 (gal)	175240
	Phosphonate (ppm)	1
Cooling Tower		
	Conductivity (µS)	422.7
	pH	8.5
	Phosphonate (ppm)	3
	P-Alkalinity (ppm)	10
	M-Alkalinity (ppm)	130
	T-Alkalinity (ppm)	140
	Hardness (ppm)	145
	Silica (ppm)	70
	Chlorides (ppm)	30
	Iron (ppm)	0
	Turbidity (NTU)	0.4
	Blow-Down Water Since 5/10/04 (gal)	63775
	Bacteria (CFU/ml)	<10,000
	Fungi/Yeast	None Detected
Cycle Calculations		
Based on Conductivity	2.4	
Hardness	2.2	
Chlorides	1.5	
Water Meter	2.7	

Monthly Water Test Results

Date	Location	
14-Jul-04	MCI	Result
Make- Up Water		
	Conductivity (µS)	200
	pH	7.3
	P-Alkalinity (ppm)	0
	M-Alkalinity (ppm)	75
	T-Alkalinity (ppm)	75
	Hardness (ppm)	80
	Silica (ppm)	30
	Chlorides (ppm)	50
	Iron (ppm)	0
	Turbidity (NTU)	0.8
	Make-Up Water Since 6/14/04 (gal)	175269
	Phosphonate (ppm)	2
Cooling Tower		
	Conductivity (µS)	453
	pH	8.2
	Phosphonate (ppm)	2
	P-Alkalinity (ppm)	25
	M-Alkalinity (ppm)	200
	T-Alkalinity (ppm)	225
	Hardness (ppm)	230
	Silica (ppm)	80
	Chlorides (ppm)	100
	Iron (ppm)	0
	Turbidity (NTU)	0.05
	Blow-Down Water Since 6/14/04 (gal)	64097
	Bacteria (CFU/ml)	<1000
	Fungi/Yeast	None Detected
Cycle Calculations		
Based on Conductivity	2.3	
Hardness	2.9	
Chlorides	2.0	
Water Meter	2.7	

Heat Exchanger Log Data

		Incoming Condenser Water		Outgoing Condenser Water			
Date	Time	Temp (Deg. F)	#18 Pressure (PSI)	Temp (Deg. F)	#2 Pressure (PSI)	Differential Temperature (Deg. F)	Differential Pressure (PSI)
1/12/2004	912	52	20	58	3	6	17
2/10/2001	1000	46	14	53	2	7	12
2/10/2004	1530	54	14	62	3	8	11
2/17/2004	1030	57	13	66	3	9	10
2/20/2004	1400	55	13.5	63	3	8	10.5
2/25/2004	1430	56	13.5	66	3	10	10.5
3/2/2004	1230	56	13.5	64	3	8	10.5
3/13/2004	900	60	12	70	2	10	10
3/19/2004	1300	64	11	74	2	10	9
3/26/2004	1250	56	11	64	2	8	9
3/29/2004	1030	62	11	72	2	10	9
4/8/2004	1330	64	9	74	2	10	7
4/16/2004	930	56	8	64	2	8	6
4/26/2004	900	66	9	75	2	9	7
4/28/2004	745	60	10	68	3	8	7
5/3/2004	800	60	10	70	2	10	8
5/10/2004	1340	60	10	67	3	7	7
5/17/2004	900	60	10	68	3	8	7
5/25/2004	1000	65	9	74	3	9	6
6/14/2004	912	67	9	74	3	7	6
6/28/2004	1030	66	9	74	3	8	6
6/29/2004	900	64	9	74	3	10	6
7/7/2004	1000	66	9	74	2	8	7
7/12/2004	1430	70	9	79	2	9	7
7/14/2004	1545	69	9	77	2	8	7