ARTHUR FREEDMAN ASSOCIATES, INC.
1415 Crystal Court Naperville, IL 60563 ph (630) 857-3094 fax (630) 689-5714 Artfreed@comcast.net

ASSESSMENT OF CHLORIDE IMPACT FROM SAVANNAH HARBOR DEEPENING

Prepared for:

SEPI Engineering & Construction
Raleigh, North Carolina 27605
and
U.S. Army Corps of Engineers
Savannah District
Savannah, GA

Prepared by:

Arthur J. Freedman, Ph.D.
Jack Soost, CWT
Arthur Freedman Associates, Inc.
Naperville, IL

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QUALIFICATIONS

Following are descriptions of the qualifications and experience of Arthur Freedman Associates, Inc. and the principle authors of this report. Detailed résumés and a more complete description of company activities are included in the Appendix.

Arthur Freedman Associates, Inc.

Arthur Freedman Associates, Inc. is a full service water management and consulting firm headquartered in Naperville, IL, near Chicago. The company has been actively in business since 1981, serving clients throughout the United States and in Canada, Mexico, Great Britain, Germany and the Far East. The client list includes large industrial plants, light industrial and HVAC systems, municipal water plants and oil production facilities. Company expertise covers failure analyses, treatment program evaluations and comparisons of alternatives, audits of water treatment operations and related work, in industrial plants, HVAC facilities, municipal water plants and oil field operations. Expertise of principle consultants is described below.

Arthur J. (Art) Freedman, Ph.D.

Dr. Freedman is a Ph.D. inorganic chemist with fifty-seven years of active experience in the water treatment industry. He worked for Amoco Oil Company for five years, for Nalco Chemical Company (a major international water treatment company) for twenty-two years, and he has managed his own water treatment consulting firm since 1981. His range of consulting experience includes potable, cooling, boiler and waste water work for large and small industrial, commercial and municipal clients. Dr. Freedman has authored approximately fifty publications, including book chapters, technical papers, presentations, and technical training manuals. He is a fifty year emeritus member of the American Chemical Society and NACE International, and Arthur Freedman Associates, Inc. is a corporate member of the Association of Water Technologies (AWT) and the Cooling Technology Institute (CTI). NACE International presented Dr. Freedman with its Distinguished Service Award in 1999 for his work chairing committees and technical symposia, and in year 2000, the AWT gave Dr. Freedman the Ray Baum Award for Water Technologist of the Year. Dr. Freedman's home and corporate office are in Naperville, Illinois, near Chicago.

W. John (Jack) Soost, CWT

Mr. Soost is a forty-eight year veteran of the water treatment industry. He holds a Bachelor's Degree in chemical engineering and a Certified Water Technologist (CWT) certificate from the Association of Water Technologies (AWT). He worked for five years for Calgon Corporation (now part of Nalco Company), fourteen years in the Consulting Services Division of Betz Laboratories (now GE Water Technologies), a major international water treatment company, and for sixteen years as Technical Director and Vice president of Engineering for Eastern Technologies, Inc. (ETI), a supplier of products, services and technology to many regional water treatment companies. His experience includes water treatment and problem-solving in potable and process water supplies, cooling and heating systems, steam generation and waste water systems in large and small industrial and commercial facilities. Mr. Soost is a member of the American Chemical Society ACS), the American Water Works Association (AWWA), NACE International, the Cooling Tower Institute (CTI) and the Association of Water Technologies (AWT). In 2010, the AWT gave Mr. Soost its Ray Baum Award for Water Technologist of the Year. Mr. Soost's home and office are in Lancaster, Pennsylvania.

Robert C. (Bob) Cunningham, P.E.

Mr. Cunningham has forty-nine years of varied experience in the water treatment industry. He holds a B.S. degree with post-graduate work in chemistry and a certified corrosion specialist (CSS) certificate from NACE International. He is a registered professional corrosion engineer in the State of California. Mr. Cunningham worked for Betz Laboratories (Now GE Water Technologies) and Calgon Corporation (now part of Nalco company), and for twenty-five years managed his own regional water treatment company serving clients in California and the south pacific islands. His water treatment consulting experience includes boiler, cooling and waste water, and potable water treatment, in large industrial plants, commercial HVAC systems and oil production facilities. Mr. Cunningham also manages Arthur Freedman Associates' water treatment laboratory, located at his office in Trinity Center, California.

ACKNOWLEDGEMENT

The authors wish to acknowledge and thank the U.S. Army Corps of Engineers, Savannah District; the City of Savannah Water Department; Tetra Tech in Atlanta, GA; SEPI Engineering and Construction in Raleigh, NC; International Paper in Savannah; and Weyerhaeuser in Fort Wentworth, GA, for assistance in obtaining and interpreting data, providing samples of water and water treatment chemicals for testing, and for commentary and advice as our work proceeded. Help from all parties in understanding the complex river and sea water flows in Savannah Harbor, and predictions of the effects of chloride intrusions in the river on municipal and industrial uses of the Savannah I&D water are greatly appreciated.

BACKGROUND AND METHODOLOGY

The proposed Savannah Harbor Expansion Project (SHEP), will allow more salt water into the Savannah estuary, and it is expected that this may affect chloride ion concentrations at the City of Savannah industrial/domestic (I&D) water intake on Abercorn Creek. A computer model was developed by Tetra Tech (released November, 2006) to predict chloride ion concentrations at the I&D intake, with harbor deepening levels from 2 to 6 feet (44 to 48 feet depth), under various conditions of river and tidal flows(1-3). This model did not predict significant increases in chloride at the I&D intake, but after study, it was felt that the conclusions might not be accurate because of a lack of supporting data at low chloride levels.

New data were collected by the City of Savannah and the United States Geological Survey (USGS). The USGS monitors flow, conductivity (salinity), temperature and chloride levels in the Savannah River estuary. Tetra Tech used USGS data from July through December, 2009 as the basis for their modeling work, and in December, 2010 they issued a revised and expanded chloride ion predictive modeling program(4). This new model does predict occasional increases in chloride levels, during periods of low river flow (drought) combined with maximum lunar high tides.

Arthur Freedman Associates, Inc. (AFA Inc.) was contracted by SEPI Engineering and Construction, for USACE, to provide an independent technical assessment of the effects of predicted increased chloride levels at the City of Savannah I&D intake, on the city water distribution system and on municipal and industrial users of the I&D water. Tetra Tech assisted with cost opinions for mitigation options.

This report contains the following work:

- Reviews of the December, 2010 Tetra Tech report(4), and documents provided by the USACE(5-9), the City, International Paper (IP) and Weyerhaeuser.
- Interviews with personnel from each of these four organizations.
- Computer runs to: a) predict the effects of increased chloride levels at the City I&D plant on corrosion rates of steel and on maximum solubilities of copper and lead; and b) the use of increased lime feed to mitigate these effects by incrementally increasing the pH of the water.
- A bench scale range-finding study to support the computer calculations and provide initial data on the corrosion rates of copper and lead before and after feeding lime to adjust pH.
- Recommendations for alternative approaches, if needed, to help mitigate corrosion of steel and levels of soluble copper and lead, and to help reduce levels of trihalomethanes (THM) and trihaloacetic acids (THAAC).
- Cost opinions for mitigation options by Tetra Tech.

THE CITY OF SAVANNAH INDUSTRIAL AND DOMESTIC WATER SUPPLY

Water Supplies

Table 1 contains analyses of the two City of Savannah water supplies: ground water (Floridan aquifer) and the Abercorn Creek Industrial and Domestic (I&D) supply, as supplied by the City. Two I&D analyses are shown, dated February and September, 2010. These two analyses are quite different, typical of the seasonal variability observed in this water. Annual variability caused by drought v. wet conditions, may be even greater, as discussed later in this report.

TABLE 1
City of Savannah Water Supplies

Source		Floridan Aquifer	Treated I&D	Treated I&D
Date		**No date**	**Feb. 2010**	**Sep. 2010**
Parameter	**As**		**Monthly avg. mg/L**	**Monthly avg. mg/L**
Tot. hardness	$CaCO_3$	100	33.8	47.0
Ca hardness	$CaCO_3$	78	27.6	37.8
Mg hardness	$CaCO_3$	22	6.2	9.2
M.O. alkalinity	$CaCO_3$	90	11.6	31.4
Sodium	Na	10.4	11.6	19.1
Chloride	Cl	4.4	6.6	11.3
Sulfate	SO_4	6.5	25.1	38.5
Silica	SiO_2	50	4.42	7.96
pH	pH	7.2	6.96	7.09
Spec. cond.	µS/cm	180 (TDS)	108	166
Tot. inorg. phos.	PO_4		0.66	0.95
Orthophosphate	PO_4		0.44	0.64
Total iron	Fe	0.06	0.03	0.01
Aluminum	Al	ND	0.07	0.02
Manganese	Mn	ND	0.01	0.00
Nitrate	NO_3	ND	0.29	0.30
LSI at 70 ºF	LSI	-0.7	-2.41	-1.91

Clearly, the Floridan aquifer and the I&D supply are two very different waters. These differences are significant. The higher calcium hardness and alkalinity in the aquifer water move the calculated Langelier Stability Index (LSI) of the aquifer water much closer to the neutral (zero) point com[pared to the I&D water. The LSI is an empirical index developed roughly 70 years ago for municipal water supplies, to help operators estimate the tendency of a water to precipitate calcium carbonate scale. Waters with a positive LSI tend to precipitate calcium carbonate, and those with a negative LSI tend to dissolve calcium carbonate.

It is also recognized that in municipal systems, calcium carbonate scale can provide corrosion protection. Hence, waters with a positive LSI were termed "scaling" and those with a negative LSI were termed "corrosive." This is a misnomer, because high LSI waters can also be very corrosive if the calcium carbonate scale does not form uniformly. Nevertheless, calculated LSI values match practical experience, that low hardness, low alkalinity waters, (and correspondingly low LSI values), like the I&D waters in Table 1, are more corrosive than more neutral LSI waters like the Floridan aquifer. Also, the presence of 50 mg/L of silica, a known corrosion inhibitor for steel, helps to make the Floridan aquifer water much less corrosive to steel than the I&D water.

These effects of alkalinity are important in understanding proposals to reduce steel corrosion rates in the I&D water with added chloride levels, and in proposals for mitigating water problems in industrial facilities that use either I&D or Floridan aquifer water, or both, in their operations.

Predicted Chloride Levels At The I&D Intake

The following data are taken from the December 31, 2010 final revised report entitled: “Chloride Modeling, Savannah Harbor Expansion Project(4),” as interpreted in the USACE document, “Chloride Impact Evaluation, January 28, 2011(9).”

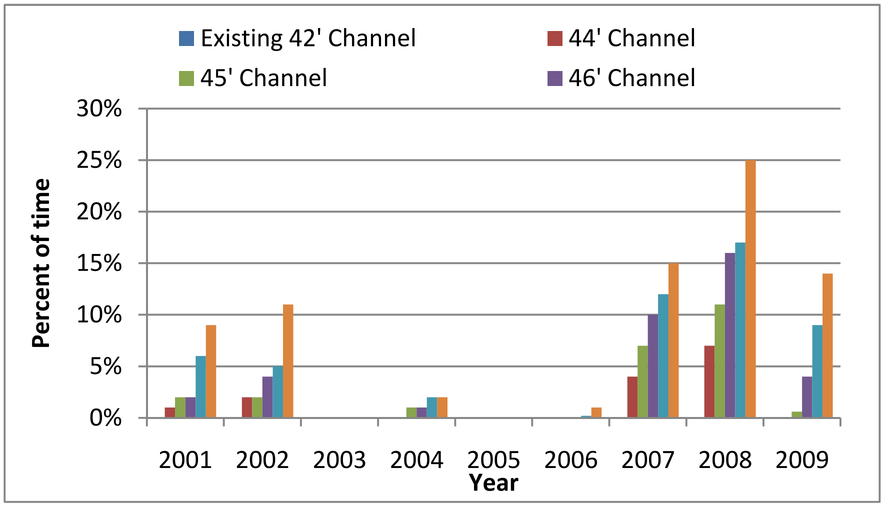
The existing depth in Savannah Harbor is 42 feet, and the base chloride level at the City I&D plant is approximately 12 mg/L. As explained in the chloride modeling report(4), chloride intrusions reaching the City I&D plant require the simultaneous occurrence of low river flow due to drought conditions and unusually high tides associated with the new moon phase. Using modeling data for the years from 2001 through 2009, Figures 1 and 2 show the calculated percentage of time that chloride levels rose to above 25 mg/L and above 50 mg/L, respectively, for harbor deepening levels from 44 to 48 feet.

25 mg/L is just a little more than double the chloride level at the I&D plant on Abercorn Creek, at the present 42 foot harbor depth. Figure 1, on the following page, shows, for years 2001 through 2009, the percent of time that modeled chloride levels surged above 25 mg/L, for harbor deepening levels from 42 to 48 feet. In 2008, a serious drought year, modeled chloride levels were above 25 mg/L about 25 percent of the time, at 48 foot deepening.

In 2007, modeled intrusions above 25 mg/L occurred 15 percent of the time at 48 foot deepening. By comparison, at 46 foot deepening, chloride intrusions above 25 mg/L occurred 15 percent of the time in year 2008, and 10 percent of the time in year 2007. Figure 1 shows that for other deepening levels and other years, chloride intrusions above 25 mg/L were all at lower levels. No intrusions occurred in years 2003 and 2005.

FIGURE 1

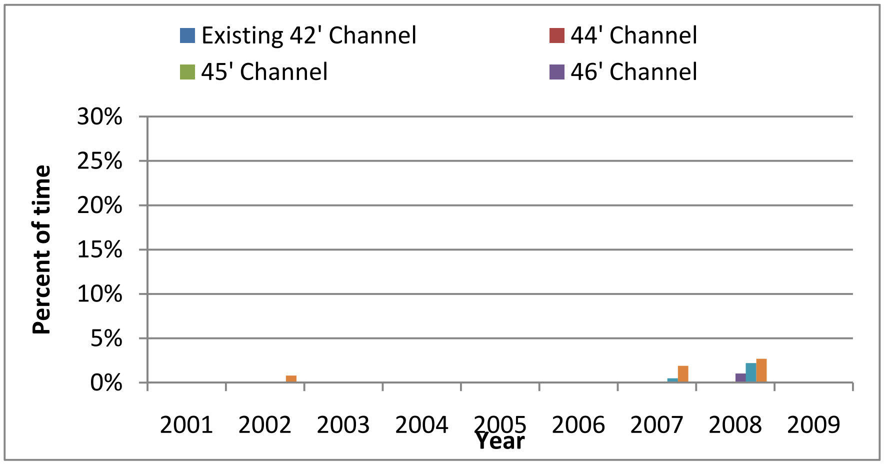
Percent of Time Calculated Chloride Levels Above 25 mg/L



50 mg/L is more than 4 times the present chloride level in the Savannah River. Figure 2, similar to Figure 1, shows the calculated percentage of time that chloride levels surged above 50 mg/L, at harbor deepening levels from 44 to 48 feet.

FIGURE 2

Percent of Time Calculated Chloride Levels Above 50 mg/L



Clearly, most of the modeled chloride intrusions above 25 mg/L (Figure 1) did not reach 50 mg/L (Figure 2). Maximum intrusions above 50 mg/L occurred 3 percent of the time in 2008 and 2 percent in 2007, at 48 foot harbor deepening. Calculated choride intrusions also occurred 2.5 percent of the time in 2008 at 47 foot deepening.

In addition to the size of calculated chloride intrusions, the time span over which chloride intrusions continue is also important. The chloride modeling data(4) show that with normal or high river flow, intrusions should be flushed back downriver with the following low tide. However, the report states that under drought conditions, as in 2008, there might not be enough river flow to flush chlorides quickly. Under these conditions, the chloride modeling program shows that chloride intrusions at the City I&D plant might last for a week or more, depending mostly on river and tidal flows.

It is important to remember that the data in Figures 1 and 2 are calculated, not real values. The nine years from 2001 through 2009 include two drought years (2007 and 2008), two especially “wet” years (2003 and 2005) and five years of roughly average river flow. The data therefore illustrate the chloride level intrusions that might be expected as river flows and tide conditions change in the future. Such changes are entirely predictable. That is, drought conditions and low river flows will be known, and expected tidal ranges will be available.

The following section of this report discusses predicted effects of increased chloride levels at the City I&D plant, and possible measures that can be taken to mitigate these effects.

EFFECTS OF INCREASED CHLORIDE ON THE I&D WATER SUPPLY

This section of the report examines the effects of increased chloride levels at the City of Savannah Abercorn Creek I&D station on corrosion rates of steel and methods that could be used to mitigate these corrosion rates.

We used a commercially available data management program, WatSim®, to study the effects of increasing chloride levels on the composition of the City of Savannah I&D plant treated water, and the possible effects of water additives in mitigating these effects. These additives might increase the pH of the water. We considered the effects of a pH increase on the production of trihalomethanes (THM) and trihaloacetic acids (THAAC) in the water. THM and THAAC are regulated by the Environmental Protection Agency and may not exceed prescribed limits.

The WatSim program uses a database of thermodynamic solubility data and measured corrosion rates to predict the effects of pH changes, added water components such as chloride, and additives, such as lime, on the composition and properties of a given water source, in this case the I&D supply. The WatSim program is described in detail, with background and reference information, in the Appendix to this report.

In order to cover a range of seasonal variability, two sets of conditions were chosen for the WatSim study:

- February, 2010 average I&D water composition, at 54.1 °F.
- September, 2010 average I&D water composition, at 83 °F.

Water analyses for these two months are shown in Table 1, above. The water is significantly more concentrated in September than in February, as shown by the chloride values: 6.63 mg/L in February and 11.31 mg/L in September. We selected these months from the data supplied by the City because we believe they reasonably represent the range of water compositions observed in the City data.

pH Adjustment and Corrosion Control With Lime

The WatSim program was used to calculate the effects of pH and alkalinity adjustment, using lime, on the composition and properties of the two I&D waters in Table 1. For each lime addition, the program calculates the resulting water composition, saturation levels for various scale-forming compounds, simple indices such as the LSI, maximum levels of soluble lead and copper ions, and the corrosion rate of mild steel in this water. Pertinent data from the WatSim runs are shown in Tables 2 and 3, and the complete WatSim runs are contained in the Appendix. Table 4 summarizes important parameters for the base level and two additional levels of lime addition. For comparison, Table 4 also contains similar data for the Savannah Floridan ground water supply.

TABLE 2

Effects of pH Adjustment using Lime: February, 2010 I&D Water at 54.1 ºF

Anal. #	pH	Chloride mg/L	Lime added mg/L	Steel corr. rate mpy	Max. soluble copper, mg/L	Max. soluble lead, ug /l
1	6.96	6.63	0.20	31.62	5.00	77.38
	7.13	6.63	5.64	17.93	3.23	39.40
	7.31	6.63	12.83	10.05	2.31	20.08
	7.48	6.63	22.34	5.57	1.80	10.24
	7.65	6.63	34.91	3.05	1.49	5.23
	7.83	6.63	51.53	1.65	1.29	2.68
	8.00	6.63	73.50	0.89	1.15	1.37
2	6.96	25	0.20	47.47	5.11	77.84
	7.13	25	5.64	26.95	3.28	39.62
	7.31	25	12.83	15.13	2.35	20.18
	7.48	25	22.34	8.40	1.83	10.29
	7.65	25	34.91	4.61	1.51	5.26
	7.83	25	51.53	2.50	1.31	2.69
	8.00	25	73.50	1.34	1.16	1.38
3	6.96	50	0.20	58.38	5.23	78.38
	7.13	50	5.64	33.19	3.36	39.89
	7.31	50	12.83	18.66	2.39	20.31
	7.48	50	22.34	10.37	1.86	10.35
	7.65	50	34.91	5.20	1.54	5.28
	7.83	50	51.53	3.10	1.32	2.70
	8.00	50	73.50	1.67	1.18	1.38
4	6.96	70	0.20	64.39	5.32	78.77
	7.13	70	5.64	36.64	3.41	40.07
	7.31	70	12.83	20.62	2.43	20.4
	7.48	70	22.34	11.48	1.88	10.4
	7.65	70	34.91	6.31	1.55	5.31
	7.83	70	51.53	3.43	1.34	2.71
	8.00	70	73.50	1.85	1.19	1.39

TABLE 3

Effects of pH Adjustment using Lime: September, 2010 I&D Water at 83 ºF

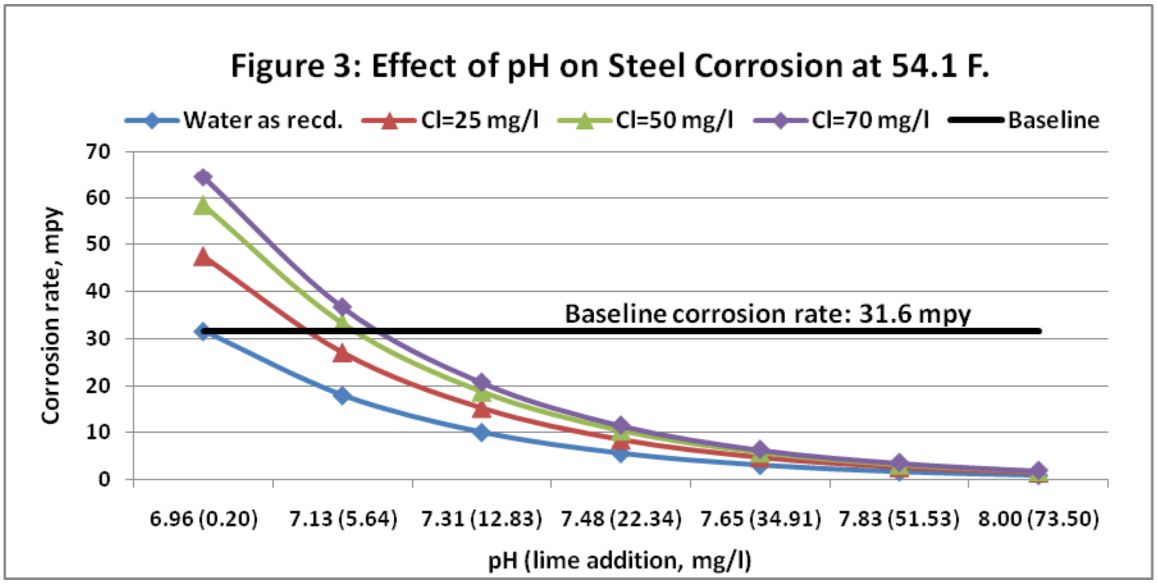
Anal. #	pH	Chloride mg/L	Lime added mg/L	Steel corr. rate mpy	Max. soluble copper, mg/L	Max. soluble lead, µg /l
5	7.09	11.31	0.21	73.59	1.12	35.69
	7.24	11.31	6.65	44.38	0.87	19.09
	7.39	11.31	14.87	26.52	0.71	10.22
	7.55	11.31	25.36	15.70	0.61	5.48
	7.70	11.31	38.76	9.22	0.53	2.94
	7.85	11.31	55.86	5.38	0.48	1.58
	8.00	11.31	77.70	3.12	0.44	0.86
6	7.09	25	0.21	93.69	1.13	35.75
	7.24	25	6.65	56.54	0.88	19.12
	7.39	25	14.87	33.79	0.72	10.23
	7.55	25	25.36	20.00	0.62	5.48
	7.70	25	38.76	11.74	0.54	2.94
	7.85	25	55.86	6.83	0.49	1.58
	8.00	25	77.70	3.95	0.45	0.85
7	7.09	50	0.21	115.0	1.16	35.90
	7.24	50	6.65	69.67	0.89	19.19
	7.39	50	14.87	41.70	0.73	10.27
	7.55	50	25.36	24.72	0.63	5.50
	7.70	50	38.76	14.52	0.55	2.95
	7.85	50	55.86	8.47	0.49	1.58
	8.00	50	77.70	4.90	0.46	0.85
8	7.09	70	0.21	127.2	1.17	36.01
	7.24	70	6.65	76.94	0.91	19.25
	7.39	70	14.87	46.09	0.74	10.30
	7.55	70	25.36	27.35	0.63	5.51
	7.70	70	38.76	16.09	0.56	2.95
	7.85	70	55.86	9.39	0.50	1.59
	8.00	70	77.70	5.44	0.46	0.85

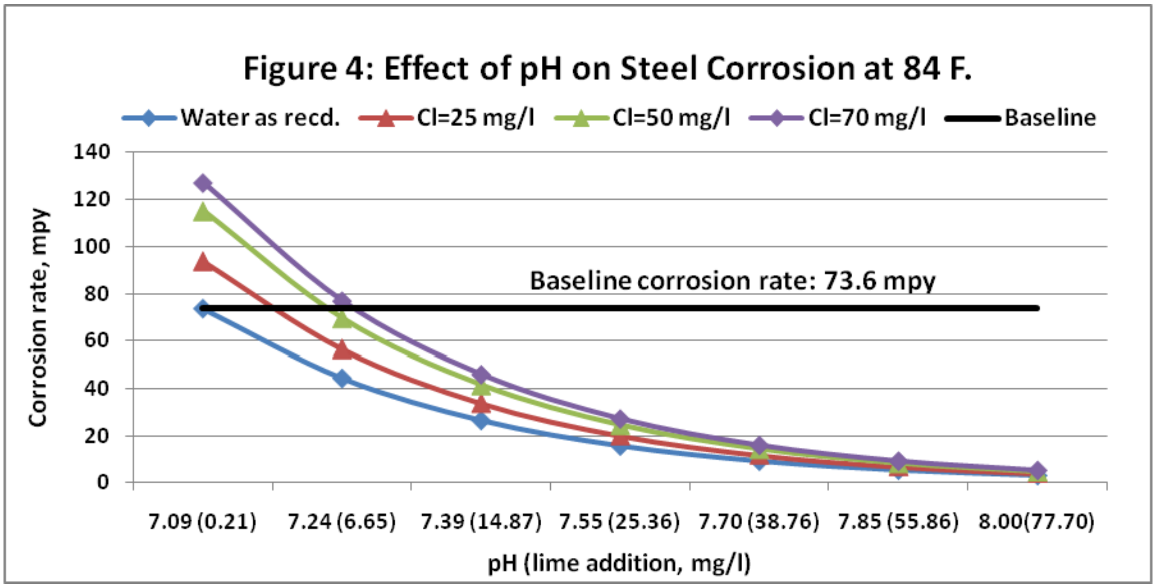
TABLE 4

Effects of Lime Additions on Savannah River Water Properties

	Current	10-15 ppm lime	15-25 ppm lime	25-35 ppm lime
Savannah Well Water - Nov. 2010 Average at 70 F				
pH for WatSim Study and Data Shown	7.8	NA	NA	NA
LSI - Langelier Saturation Index	-0.37	NA	NA	NA
Steel Corrosion Rate - mils/year - mpy	0.47	NA	NA	NA
Max. Solubility of Copper Species - mg/L (ppm)	1.91	NA	NA	NA
Max. Solubility of Lead Species - ug/l (ppb)	2.35	NA	NA	NA
Savannah I&D Water - Feb. 2010 Average at 54 F				
pH for WatSim Study and Data Shown	6.96	7.31	7.48	7.65
LSI - Langelier Saturation Index	-2.31	-1.49	-1.08	-0.69
Steel Corrosion Rate - mils/year - mpy	31.6	10.1	5.57	3.05
Max. Solubility of Copper Species - mg/L	5	2.3	1.8	1.5
Max. Solubility of Lead Species - ug/l	77.4	20.1	10.2	5.2
Savannah I&D Water - Sept. 2010 Average at 83 F				
pH for WatSim Study and Data Shown	7.09	7.39	7.55	7.7
LSI - Langelier Saturation Index	-1.59	-0.9	-0.55	-0.21
Steel Corrosion Rate - mils/year - mpy	73.6	26.5	15.7	9.2
Max. Solubility of Copper Species - mg/L (ppm)	1.12	0.71	0.61	0.53
Max. Solubility of Lead Species - ug/l (ppb)	35.7	10.2	5.5	2.9
Savannah I&D Water - Feb. 2010 Avg. With 50 Cl at 54 F				
pH for WatSim Study and Data Shown	6.96	7.31	7.48	7.65
LSI - Langelier Saturation Index	-2.35	-1.51	-1.11	-0.71
Steel Corrosion Rate - mils/year - mpy	58.4	18.66	10.37	5.7
Max. Solubility of Copper Species - mg/L (ppm)	5.23	2.39	1.86	1.5
Max. Solubility of Lead Species - ug/l (ppb)	78.4	20.3	10.4	5.3
Savannah I&D Water - Sept. 2010 Avg. With 50 Cl at 83 F				
pH for WatSim Study and Data Shown	7.09	7.39	7.55	7.7
LSI - Langelier Saturation Index	-1.62	-0.92	-0.57	-0.22
Steel Corrosion Rate - mils/year - mpy	115.3	41.7	24.7	14.5
Max. Solubility of Copper Species - mg/L (ppm)	1.16	0.73	0.63	0.55
Max. Solubility of Lead Species - ug/l (ppb)	35.9	10.3	5.5	2.9

It is important to remember that the data in Tables 2, 3 and 4 are calculated values, based on the chemical analyses in Table 1. The calculated corrosion rates are, in some cases, higher than would be expected in the field. This happens because the rates are calculated on clean steel, and many site-specific factors that affect corrosion rates cannot adequately be included in computer programs. Flow rates, holding times, dissolved organic matter in the water but not included in the analyses, intentionally added corrosion inhibitors, deposited films on metal and other factors all can affect corrosion rates. What is important to note in these Tables is the relative rates and the changes that result from changes in water composition.





Figures 3 and 4 show the effect of temperature, pH and chloride level on the corrosion rate of steel in water. The two graphs show clearly that the difference in water chemistry, and raising the temperature from 54 to 83 ºF increases the calculated steel corrosion rate from 31.6 to 73.6 mpy. This is in line with a water treatment "rule of thumb" that raising the water temperature 10 ºC roughly doubles the corrosion rate.

Adding 25, 50 and 70 mg/L of chloride to the water also dramatically increases the corrosion rate. It is well known that increasing the dissolved solids (conductivity) of the water allows more corrosion current to flow and increases the corrosion rate. Chloride ions exacerbate this effect by forming very stable, soluble complexes with ferrous and ferric ions as they are formed.

Another well-known water treatment guideline is that adding lime (calcium hydroxide) to water increases the pH and alkalinity and reduces corrosivity to steel. Lime also adds calcium hardness, another beneficial factor in corrosion control. Thus, Figures 3 and 4 show clearly that raising the pH of the water about 0.2 pH units by lime addition, at any chloride level, reduces the corrosion rate to about the baseline chloride level.

This leads to one recommended method for mitigating the effects of chloride intrusions. Adding between 5 and 15 mg/L of lime, beyond what is already used, should maintain corrosion rates on steel at about the level with no chloride intrusions. The City already adds lime for corrosion control, so increasing the amount used to adjust water composition after clarification and filtration should not be difficult.

A very important consideration for the City of Savannah, and for all municipalities, is the levels of soluble copper and lead ions in the water. These levels are strictly regulated by the USEPA. Tables 2, 3 and 4 show clearly that adding up to 70 mg/L chloride to the water, at either 54 or 83 ºF, does not change the calculated solubility levels of lead and copper, and that adding lime to the water significantly reduces these solubilities. The bench scale corrosion studies now in progress will provide initial data on corrosion rates of copper and lead, as well as steel.

In addition to pH control with lime or other chemicals, specific corrosion inhibitors are commonly used to help control corrosion in municipal water systems. The City currently adds phosphate to help maintain low levels of soluble copper and lead in the water, and this certainly should be continued or increased. Silicate is often used in municipal systems to protect steel, cast iron and wrought iron pipe. Savannah has good evidence for the efficacy of silicate in controlling corrosion, from the high silicate level and low corrosion rates in the ground water systems (see Table 1).

THM and THAAC Formation

There are, however, other factors that affect chemical treatment, allowable pH levels and corrosion control in municipal water systems. These factors cannot easily be predicted because they are site-specific. They do not affect the WatSim computer calculations as shown in this report, but they may affect the dosages of chemicals that can be used and the results that can be achieved.

One such variable is the trihalomethane (THM) level, also regulated by the USEPA along with other disinfection byproducts (DBP). The City indicated that the need to control THM levels may create an upper pH limit in the I&D water of about 7.8. Tables 2, 3 and 4 show that pH 7.8 is above the pH and lime addition levels projected by WatSim to maintain steel corrosion rates at current levels during short term, temporary chloride intrusions.

THMs are formed by the reaction of chlorine or bromine with certain unsaturated organic compounds. Their formation is favored by higher pH levels in the water. A related series of compounds, trihaloacetic acids (THAAC) form at lower pH levels(19). Any procedure for pH adjustment to control corrosion of steel during chloride intrusions must include a careful assessment of THM and THAAC formation under operating conditions.

If needed, methods are available for mitigating the THM/THAAC problem by removing the reactive organic compounds from the water before chlorination. One of two processes are used for this purpose:

- Ozonation: Ozone is a powerful oxidizing gas that can be mixed into water to destroy reactive organic compounds that would otherwise react with chlorine to form DBP such as THM and THAAC. Ozone is unstable and must be prepared on-site and used immediately. Preparation involves passing oxygen, or dry air, through an electrical corona discharge. The main operating cost is electric power. A disadvantage of ozone is that it will oxidize bromide ions brought in with sea water, to bromate, a regulated ion. An ozone cost assessment is included in the Appendix to this report.
- Granular activated carbon (GAC): Activated carbon adsorbs soluble reactive organic molecules, thus removing them from the water. Water is passed over beds of granular activated carbon in tanks. The carbon requires regular regeneration and occasional replacement. An activated carbon cost assessment is included in the Appendix to this report.

Both ozonation and GAC can be used in a split-stream mode, in which a portion of the total water flow is treated and the remainder is not treated. The two streams are then recombined. The relative flows in the two streams can be varied to produce the desired reduction in THM and THAAC levels.

Summary and Recommendations

1. The frequency, height (chloride level) and duration of chloride intrusions at the City of Savannah I&D water plant on Abercorn Creek will depend on the level of deepening in Savannah Harbor, rate of flow in the Savannah River, and tidal flow in the harbor. These intrusions will be highly predictable, in both height and duration. They will depend upon known drought conditions in the river and known special high tides, (sometimes called new moon high tides).

2. Calculations using the WatSim data management program have shown that:
   - Raising the water temperature from 54 to 84 ºF (as from winter to summer) roughly doubles the corrosion rate of steel in Savannah River water.
   - Increasing the chloride level in the water from a maximum of about 18 mg/L to about 70 mg/L will also double the corrosion rate of steel. Intrusions of this magnitude will occur about three percent of the time, and only at the 48 foot harbor deepening level, based on the chloride modeling study of river data for the years 2000 to 2009. Lower level and shorter intrusions will occur more frequently.
   - Adding lime in the range of 5 to 15 mg/L, to raise the pH of a high chloride water by about 0.2 pH units, will reduce the corrosion rate of steel to the value in that water at baseline chloride level or below. This effect occurs at all tested chloride levels and at both 54 and 84 ºF.
   - Maximum solubility levels of copper and lead species do not change with increasing chloride levels or with lime additions.
3. Other known corrosion inhibitors, e.g. phosphates and silica, should have similar effects in reducing steel corrosion rates. These were not evaluated in the WatSIm program.
4. Based on these data, it should be possible to develop a management program to control lime additions to the I&D water, after coagulation and filtration, based on seasonal changes and predicted drought and tidal flows.
5. Lime additions as described above will raise the pH of the I&D water from 7.0-7.2 to about 7.2-7.5. The effect of this pH change on levels of THM and THAAC in the water must be determined by on-site testing. Mitigation of THM and THAAC, if needed, can be accomplished by treatment of the water with granular activated carbon (GAC) or ozone. Cost estimates for GAC and ozone are included in the Appendix.

BENCH SCALE LABORATORY CORROSION STUDY

The corrosion results reported in the previous section of this report are calculated values, using the WatSim program. A bench scale laboratory study was conducted to provide experimental verification of the WatSim steel corrosion rate data and to generate copper and lead corrosion rate data to parallel the WatSim program predictions for maximum solubilities for copper and lead species. This study involved water shipped from the Savannah I&D plant to the laboratory, and corrosion measurements using the linear polarization method.

The Linear Polarization Method for Corrosion Measurements in Water Systems

Corrosion of metals in water systems is an electrochemical process. This means that at some point on a metal surface in water, called an anode, metal atoms are oxidized to form positively charged metal ions in the water, leaving behind electrons in the metal. These electrons flow to other spots on the metal surface, called cathodes, where substances in the water, usually dissolved oxygen, absorb these electrons and are reduced to form negatively charged hydroxide ions. The positive and negative ions flow through the water and react to form corrosion products, usually as solid deposits. The flow of electrons through the metal and ion through the water is called the corrosion current, and the magnitude of this current is proportional to the corrosion rate of the metal. Basic electrochemical corrosion mechanisms are explained in detail in many textbooks and reference publications(21, 22, 23).

If the corrosion current passing between anodic and cathodic areas on a metal surface, as explained above, could be measured, then the corrosion rate could be calculated. This is not possible, however, because the anodes and cathodes are on the same piece of metal and sometimes microscopically close together. To measure the corrosion current, the anodic and cathodic areas must be separated. This can be done by exposing two electrodes of the same metal in a solution and applying a small (millivolt) potential difference between them. Now one electrode becomes the anode and the other the cathode, and the resulting current can be measured. Because the applied potential difference is small, the natural corrosion reactions are not disturbed, and the current that flows between the electrodes is controlled by the same factors that control the natural corrosion rate.

One important factor affecting aqueous corrosion rates is polarization; that is, the tendency of corroding surfaces to become polarized, or protected, by accumulations of corrosion products, gas bubbles and other materials on the surface. This tends to interfere with current flow and reduce the corrosion rate. Rapidly corroding surfaces will have low levels of polarization resistance, and conversely, slowly corroding or protected surfaces will have high levels of polarization resistance. With suitable instrumentation, corrosion currents and polarization resistance can be measured, and from the known applied potential and the configuration of the electrodes, corrosion rates can be calculated. This is the linear polarization resistance (LPR) method for measuring corrosion rates.

LPR corrosion rate data are reliable and reproducible. The data may or may not agree with weight loss corrosion coupon measurements, because external factors such as water flow patterns, surface deposits, etc. may affect coupons and probe electrodes differently. Most important, changes in corrosion rate resulting from a change in water composition, e.g. addition of lime or a corrosion inhibitor, such as phosphate, can be seen immediately as a change in the LPR corrosion rate. For this reason, LPR data are sometimes referred to as "instantaneous" corrosion rates. LPR instruments are widely used for monitoring and control purposes in field applications, and as laboratory tools in tests where rapid response to changes in test conditions is required(24, 25).

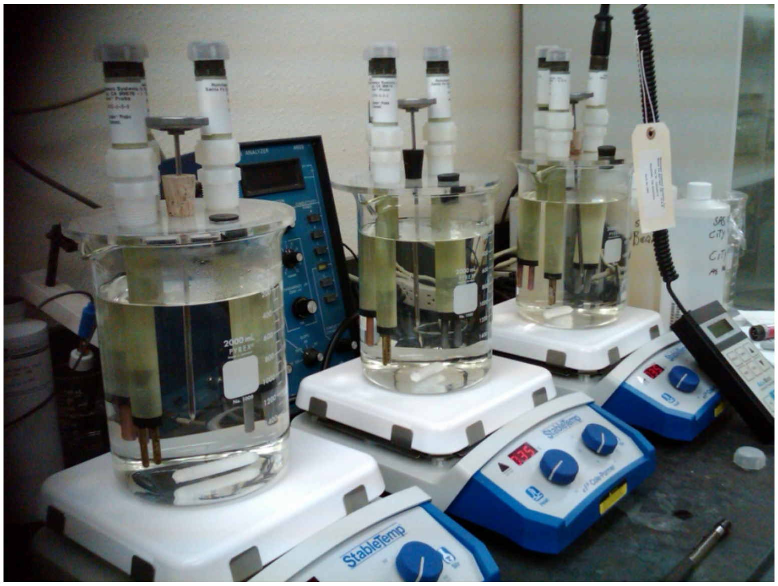
Program Objectives

There were three main objectives in this testing program:

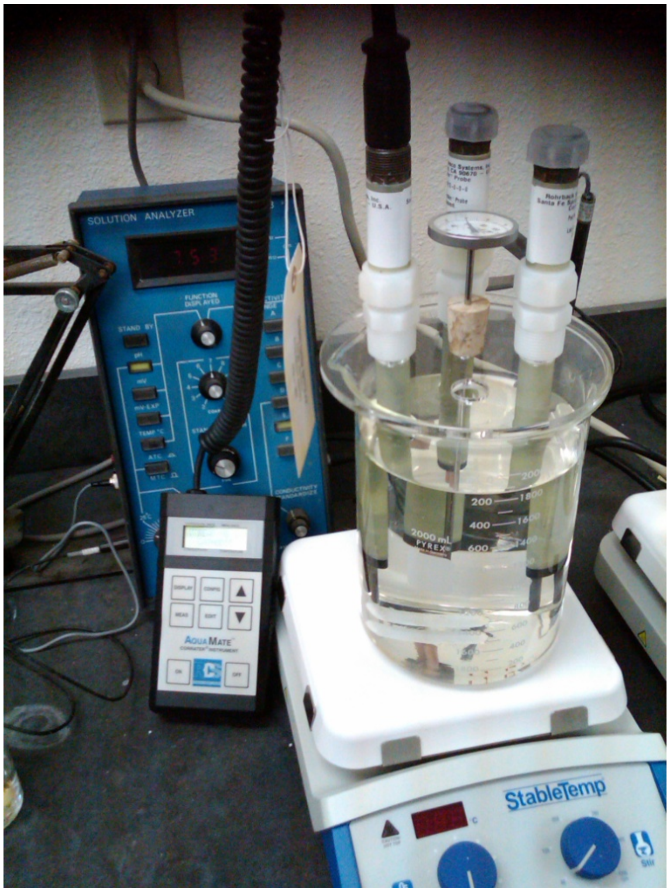
1. To validate WatSim calculations of the effects of temperature changes, chloride intrusions and lime additions on corrosion rates of steel in Savannah I&D water.
2. To estimate the effects of phosphate additions on corrosion rates of steel.
3. To estimate corrosion rates of copper and lead in I&D water.

Experimental procedures

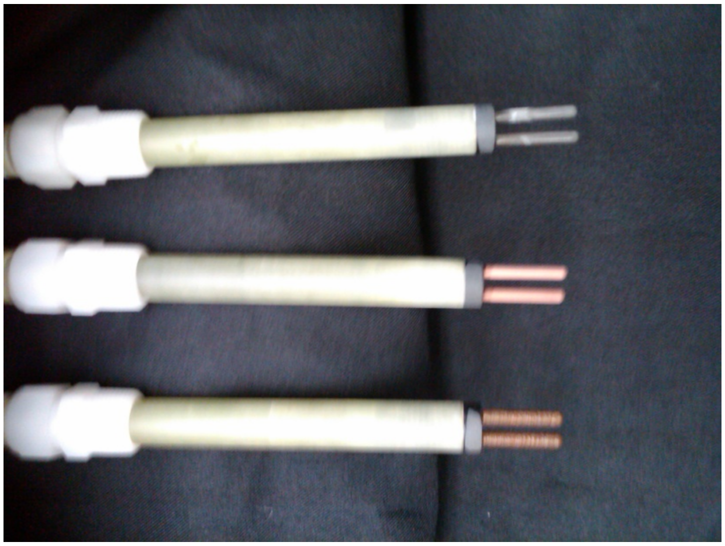
The equipment used for these tests is shown in Photographs 1, 2 and 3, below.



Photograph 1. Test cells ready to start a run.



Photograph 2. Test beaker, Aquamate™ Corrator®, probes and stirrer.



Photograph 3. Corrator® probes with steel, copper and lead electrodes.

LPR corrosion measuring equipment used in this work was supplied by the Rohrback Cosasco Company(26). Their Aquamate™ portable corrosion monitor is shown in Photograph 2 and the Model 1190 Corrator® probes and tips are in Photograph 3.

Savannah I&D water was shipped to our laboratory near Redding, CA and stored in 5 gallon plastic containers. For each run, three 2 liter beakers were filled with 1750 ml of I&D water, as shown in Photographs 1 and 2. Three Corrater probes, with steel, copper and lead tips (Photograph 3) were mounted in each beaker, along with a thermometer and magnetic stirrer.

Initial tests were run at ambient lab temperature (54-58 ºF) or heated to 84 ºF., and the probes were allowed to age for several hours before readings were taken. However, two problems developed with this procedure:

1. The waters lost carbon dioxide on stirring, and the pH rose quickly from 7.3 as received to 7.5-7.6. This interfered with our initial ability to manually adjust and control pH.
2. The I&D water as received was very corrosive to steel, with measured corrosion rates well over 10 mpy. Because these were of necessity static tests, as opposed to on-site flow through tests, corrosion products quickly accumulated in the water. Red deposits appeared on the steel probe tips and the water became yellow. Corrosion of steel in water generates ferrous and ferric hydroxides, which neutralize acid and raise the pH. Also, corrosion product deposits on the electrodes interfere with current flow, reducing the corrosion rate.

The pH control problems were managed by adding lime required for pH adjustment immediately after the beakers were filled, and by trimming the pH manually with a few drops of dilute sulfuric acid as needed. Also, for more precise temperature control, later series of tests were all run at 84 ºF.

To avoid corrosion product accumulation, the probe tips were cleaned by acid dipping, brushing and rinsing before each run, and the aging step was omitted. Readings were taken as quickly as possible after the probes were installed in the test beakers, and every 20-30 minutes thereafter for about two hours. In most tests, some longer term readings were taken, but the data show that corrosion rates remained relatively constant.

The initial probe readings do not represent equilibrium surface conditions. However, the intent of these tests is not to reproduce actual in-service corrosion rates. That requires long term exposure of metal coupons or spool pieces in flowing water, so that the surfaces can develop protective films and deposits similar to those on the system piping. Under these test conditions, initial readings were found to be the best way to compare test data and observe changes and trends under similar and reproducible conditions.

Results and Discussion

A. Validation of WatSim calculations

Figures 5, 6 and 7 compare WatSim and Corrator data illustrating how chloride levels, water temperature and lime additions influence the corrosion rate of steel in I&D water.

FIGURE 5
The Effect of Chloride on the Corrosion Rate of Steel in I&D Water

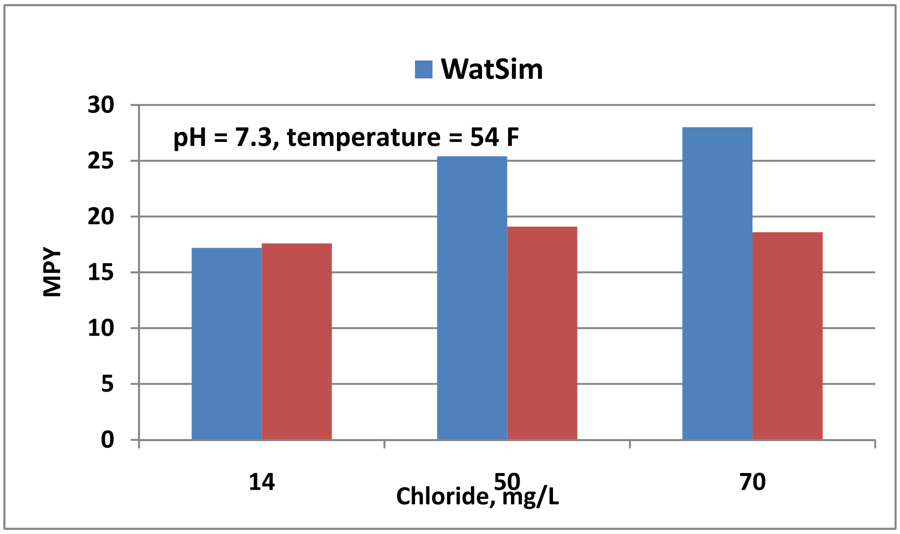


FIGURE 6
The Effect of Temperature on the Corrosion Rate of Steel in I&D Water

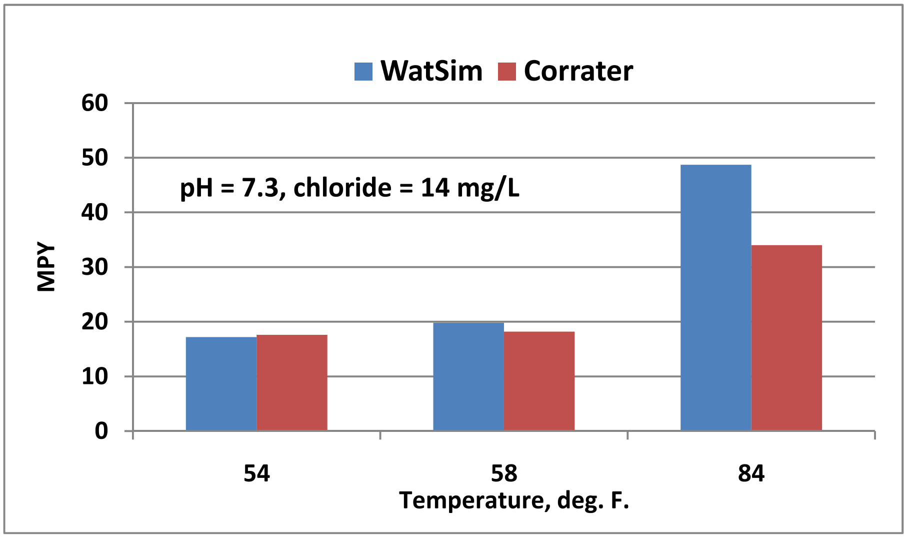
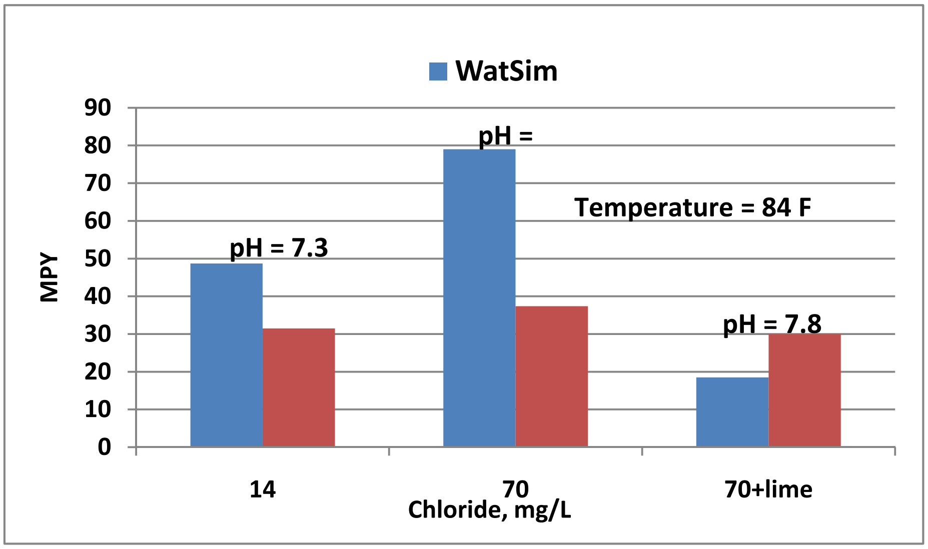


FIGURE 7
Effects of Lime Additions on the Corrosion Rate of Steel in I&D Water



The blue bars in each graph are representative WatSim calculations. The red bars are averages of several Corrater runs under each set of conditions, as shown. The trends in each graph are clear. That is, changes in calculated WatSim data parallel changes in Corrater readings, as expected.

It is important to remember that the WatSim calculations assume new, clean steel, and the corrosion rates are therefore significantly higher than field data. The Corrater tests are intended to show data on clean electrodes, but as explained earlier, the high corrosion rates we encountered, the relatively small volumes of water involved and the fact that these were confined volumes of water, not a flowing stream, all contributed to rapid production of corrosion product films. Therefore, the rates, and changes in rates, in the Corrater tests are smaller than we had expected. Nevertheless, the data are valid and there are important trends to be noted.

1. Chloride level. Chloride levels in this study were chosen to correspond to chloride intrusion ranges of 50 and 70 mg/L, as discussed earlier in this report (see Figures 1 and 2 on page 8.) The base chloride level, 14 mg/L, was measured in the I&D water as received in our laboratory for testing.

   WatSim and Corrater corrosion rate data increase with chloride content in the I&D water, as shown in Figure 5. At 54 ºF, the ratio of WatSim corrosion rates at 50 and 14 mg/L chloride is 1.48, while the corresponding ratio of Corrater data is 1.1. This is good agreement. Between 50 and 70 mg/L chloride, the WatSim data ratio is 1.1 and the corresponding Corrater data ratio is 0.97, indicating no change.

2. Temperature. The temperatures in these tests were chosen to represent extremes that might be expected in the I&D water during winter and summer months. Figure 6 shows data at both 54 and 58 ºF because that represents the range of cold temperature control achievable under the conditions of these tests. Figure 6 shows that the ratio of WatSim corrosion rates on steel at 84 and 58 ºF is 2.5, while the corresponding ratio of Corrator data is 1.9.

   Both WatSim and Corrater data show that the effect of temperature on the corrosion rate of steel in I&D water is much greater than the effect of chloride level in the water. Temperature effects are part of the City of Savannah's current operating procedures at the I&D plant, and the data in this report indicate that temperature is an important factor that should be included in plans to mitigate the effects of chloride intrusions. On-site corrosion studies would provide further information on this situation.

3. Use of lime to mitigate effects of chloride intrusions. A major objective of the Corrater study is to authenticate the use of lime to raise the pH and reduce the corrosion rate of steel in the I&D water, in the presence of chloride intrusions, as predicted by the WatSim calculations in the March 11, 2011 report.

   The data are shown in Figure 7. This work was done at 84 ºF. As in Figures 5 and 6, the blue bars represent calculated WatSim data and the red bars measured Corrater data. The first set of bars shows WatSim and Corrater data in the water as received at pH 7.3. The second set of bars shows the corrosion rates resulting from adding sodium chloride to obtain a total of 70 mg/L chloride in the water, with the pH still 7.3. Finally, the third set of bars shows the effect of adding lime to raise the pH, in this case to 7.8.

   As explained above, the effects are more dramatic with the calculated WatSim data than with the Corrater data, but the trends are the same, as predicted. Adding chloride increases the corrosion rate, and raising the pH with lime reduces the rate to the base chloride level or below. Lime is the best available choice for this purpose because it provides both bicarbonate alkalinity by reacting with carbon dioxide in the water, and calcium hardness that assists in film formation on steel. The City currently adds lime to the I&D water as part of their water preparation program, so that managing lime additions should be a relatively simple way of mitigating effects of corrosion due to chloride intrusions. On-line pilot scale testing or full plant trials will provide accurate dosage information.

B. Effect of Phosphate Additions on Corrosion of Steel

The City of Savannah adds to the I&D water about 1 mg/L (as phosphate, PO4) of a phosphate product identified only as "Pristine" phosphate. The purpose of this addition is primarily to help control corrosion of copper and lead in the distribution system and to help remove soluble copper and lead ions from the water. Phosphate is a known corrosion inhibitor for steel, and it was thought that use of additional phosphate might be another route to mitigation of corrosion from chloride intrusions at the I&D plant.

It was possible to do only a few preliminary Corrater tests with phosphate, and the results are inconclusive. This work was done by adding known quantities of phosphate to the test beakers at the end of other runs, hoping for an additional drop in corrosion rate. Following are the results of two such tests:

TABLE 5
Phosphate Test A for Corrosion Control on Steel

	Beaker A	Beaker B	Beaker C
Temp. ºF,	84	84	84
Chloride, mg/L	25	25	25
Lime addition, ml	0	10	25
pH after lime	7.3	7.6	7.8
Steel mpy, 12 hrs, avg. of 9	16.7	16.9	17.0
Pristine phosphate as PO4, mg/L	2	5	10
Steel mpy, 12 hrs after PO4 add'n	16.7	16.9	17.6

TABLE 6
Phosphate Test B for Corrosion Control on Steel

	Beaker A	Beaker B	Beaker C
Temp. ºF	84	84	84
Chloride, mg/L	14	50	70
Lime addition, mg/L	10	10	10
pH after lime	7.6	7.6	7.6
Steel mpy, 1 hr, avg. of 3	39.7	44.4	41.2
Pristine phosphate as PO4, mg/L	5	5	5
Steel mpy, 1 hr after PO4 add'n	35.1	36.2	43.6

Test A (Table 5) was a long term, 12 hour test, while test B (Table 6) ran for 1 hour. This is the reason for the higher corrosion rates in test B. In test A, there was no difference in corrosion rates 12 hours after phosphate addition. In test B, corrosion rates dropped about ten percent in beakers A and B, but increased in beaker C, probably due to the high chloride content. There is no evidence for a useful decrease in corrosion rates after phosphate addition.

C. Corrosion of Copper and Lead

Table 7, below, shows a summary of the copper and lead corrosion data collected during the Corrater testing project. Except for temperature, there were no discernable trends in the data. Therefore, the Table shows simply average data at each temperature, the number of data points included, and the range, or spread, of the data.

TABLE 7
Copper and Lead Corrater Corrosion Rates in I&D Water

Metal	Temp.º F	Avg. MPY	Data Points	Range, MPY
Copper	54	0.02	18	0.00-0.09
	84	0.25	25	0.05-0.76
Lead	54	0.32	12	0.24-0.45
	84	0.29	25	0.01-0.74

Chloride levels, pH and lime additions did not seem to have significant effects on corrosion of copper or lead. At 54 ºF, the corrosion rate on copper was very low at 0.02 mpy, and the range was small. The rate increased by a factor of 10 at 84 ºF, and the range was much wider. Lead showed a higher rate than copper at 54 ºF, but the rate did not increase at 84 ºF. As with copper, the range of data for lead was much wider at 84 ºF. These wider ranges may be related to surface preparation and cleaning of the Corrater electrodes. Any further work to study this effect should be done as part of a larger on-site pilot scale study.

Summary of Bench Scale Laboratory Test Results

Bench scale beaker Corrater tests corroborate the WatSim calculations in our March 11, 2011 report. Measured corrosion rates are lower than WatSim calculated values, and effects are smaller, as expected, but the experimental data validate the calculations.

Corrater tests of phosphate additions for corrosion control on steel are inconclusive. Further work on phosphate as a mitigation tool should be done on a pilot scale. Corrator tests in Savannah I&D water show that the water as tested, chloride additions up to 70 mg/L and lime additions up to pH 7.8 do not significantly affect corrosion rates of copper and lead.

Water temperature in the Savannah River has an important effect on corrosion of steel. Temperature should be considered a significant factor in plans to mitigate corrosion of steel caused by chloride intrusions at the I&D intake.

INDUSTRIAL PLANTS ON THE SAVANNAH RIVER

International Paper

International Paper (IP) uses city water, ground water and a mixture of these two waters. Some process units use city water, others ground water. The demineralization (boiler feedwater) system runs on ground water. Table 8 compares the analyses of the Floridan aquifer as ground water available to IP with Savannah I&D plant treated water analyses for September, 2010, and the September analysis including 50 mg/L added chloride plus 15-25 mg/L lime (WatSim data). Finally, Table 8 contains the design water treatment supply specification for the IP demineralization train.

IP expects to discontinue use of ground water within the next 5 to 10 years, and operate entirely on city water. This change in water sources is being prompted by Georgia ground water regulations and is not associated with the Savannah Harbor deepening Project. This will increase the daily cost of the IP plant water supply and will require changes in both process and demineralization systems. Mill personnel expressed concerns that they may not have sufficient demineralization capacity after switching to City water, and may have to install a pretreatment RO system to protect the ion exchange loading on their demineralizer resins. Our examination of the water analyses in Table 8 shows that IP may, in fact, gain demineralization capacity by moving from ground to I&D plant water, even with variable increases in chloride content, because of the much lower levels of silica in the I&D water, compared to ground water. However, with the variable increases in chloride levels and the higher dosages of lime that may be periodically needed to inhibit corrosion, the availability of an RO pretreatment system may be required or at least very beneficial.

IP is also concerned about the integrity of their very old underground piping system. They fear that higher chloride levels will increase corrosivity to steel and possibly hasten failures of already-weakened pipes. No water-related failures have been reported in these systems to date. As explained earlier in this report, increasing lime additions to the I&D water supply will negate the effects of chloride on steel corrosion rates. Possible additions of silicate and/or additional phosphate could further reduce the corrosivity of the I&D water, but will increase the ion exchange load on the demineralizers. However, switching from ground water to I&D water will introduce a more corrosive water to pipes currently protected by a natural high level of silicate in the ground water.

No information was provided on possible effects of increased chloride levels on IP’s process operations. For locations currently using a blend of I&D and ground water, a consistent chloride level could be maintained by changing the blend ratio during chloride intrusions

TABLE 8
Water Supply Comparisons

Source		**Floridan Aquifer**	**Treated I&D**	**Treated I&D**	**IP Design for**
Date		**No date**	**Sep. 2010**	**Sep. 2010**	**DI supply**
Parameter	**As**		**Monthly avg. mg/L**	**Plus 50 Cl, 15-25 lime**	
Tot. hardness	$CaCO_3$	100	47.0	77.8	
Ca hardness	$CaCO_3$	78	37.8	68.6	58
Mg hardness	$CaCO_3$	22	9.2	9.2	
M.O. alkalinity	$CaCO_3$	90	19.1	44.2	
Sodium	Na	10.4	31.4	65.1	30
Chloride	Cl	4.4	11.3	50.0	15
Sulfate	SO_4	6.5	38.5	38.5	
Silica	SiO_2	50	7.96	7.96	40
pH	pH	7.2	7.09	7.55	
Spec. cond.	µS/cm	180 (TDS)	166	290	
Tot. inorg. phos.	PO_4		0.95	0.95	
Orthophosphate	PO_4		0.64	0.64	
Total iron	Fe	0.06	0.01	0.02	
Aluminum	Al	ND	0.02	0.00	
Manganese	Mn	ND	0.00	0.30	
Nitrate	NO_3	ND	0.30		
LSI at 70 ºF	LSI	-0.7	-1.91		

Weyerhaeuser

Weyerhaeuser is the single largest user of City I&D water, currently 12-13 MGD, Usage was 15-16 MGD before process water cooling towers were installed. The plant does not use any ground water.

The plant also has a once-through intake that draws 12-15 MGD of estuary water near the Houlihan Bridge into the plant. The water is used in a large plant fire protection system, and also to cool the black liquor surface condenser, which operates with once through cooling water.

Weyerhauser reported that the conductivity of the estuary water varies from 8,000 to 22,000 µmhos/cm. The chloride modeling report(4) shows that during low river flow periods, the chloride level could range from about 14,000 to 17,000 mg/L, and from about 3,000 to 13,000 mg/L during high flow periods(20). Weyerhaeuser is concerned about the integrity of the piping in this system, but they are not likely to abandon the estuary water for back-up fire protection.

Weyerhaeuser's power plant includes two boilers rated at 1200 psi but currently operating at 600 psi. The plant is 99% self-sufficient for electric power. The demineralization train is running at 50-60% of rated capacity, Weyerhaeuser stated that the system can handle water with 40-50 mg/L chlorides, but these levels could be a problem if any equipment was simultaneously out of service for maintenance. Higher levels would create a problem. There is also a 489,000 gallon demineralized water storage tank available that can provide 11.4 hours of reserve water capacity. If more capacity were needed, the plant would install an RO system upstream of the demineralizers. Current I&D plant water data as supplied to Weyerhaeuser, and this water with 50 mg/L added chloride and 15-25 mg/L lime, are the same as shown in Table 4 for IP.

Weyerhauser runs an extensive water conservation system. Mill water is cooled by direct contact in cooling towers and returned to the mill circuit. There is no intentional bleed off, but the towers are operated with very low cycles of impurity concentration, controlled by process requirements to maintain specific conductance levels below 400 micromhos. Thus, an increase in chloride (conductivity) in the I&D plant water supply could require Weyerhaeuser to purchase more water, or operate a sidestream RO system to remove some of the mineral content in the process water. Cost estimates are included in the Appendix.

Weyerhaeuser's present major process use of city water is in the bleach plant. Chlorine dioxide is used to bleach pulp. Chlorides interfere with the bleaching process, so that chloride increases could create a potentially serious problem. No data are available at this time that would help us determine the extent of this problem.

Along with all other users of city I&D water, Weyerhaeuser is concerned about the integrity of their buried water piping system. The proposed increase in lime addition to the City I&D water, along with possible additions of silicate and/or additional phosphate, would help to mitigate this problem.

Additional Industrial and Commercial Users of I&D Water

The City of Savannah supplies I&D water to several other industrial users, many commercial users, and two municipalities. None of these facilities were interviewed for this report. Many of these smaller industrial and commercial facilities may use City I&D water for makeup to evaporative cooling tower water systems.

Typically, evaporative cooling systems endeavor to concentrate (cycle up) the impurities in the water supply by 5 to 6 cycles to conserve water and to optimize water treatment for control of cooling system corrosion and mineral scale deposits. Higher cycles are frequently pursued. However, operation above about 8 cycles creates treatment problems due to longer residence times for water in the tower system, without conserving much additional water.

WaterCycle® is a computer database program similar to WatSim, designed to predict water compositions, mineral solubilities and corrosion rates as water is concentrated in cooling tower systems. WaterCycle was used to investigate possible effects of increased chloride levels in the I&D water on cooling tower operations. Studies were centered on using the September 2010 City I&D waters as shown in the 3rd and 6th columns of Table 1.

The WaterCycle findings indicate that evaporative cooling systems using the I&D water supply with composition similar to the September, 2010 analysis (Table 1) can be successfully operated with at least 8 to 10 cycles of concentration, provided the circulating cooling water is chemically treated to control corrosion of system metallurgies and to inhibit scale and microbiological growths. If this water receives a chloride intrusion up to 50 mg/L and the I&D plant compensates with 15-25 mg/L lime to increase the pH, cooling tower cycles should be reduced and/or chemical treatment programs adjusted. These are small changes that are handled routinely in most cooling tower systems.

MITIGATION COST INFORMATION

This report does not include a detailed technical evaluation of mitigation options for the Savannah I&D water plant, International Paper or Weyerhaeuser. For planning purposes, Tetra Tech, Inc. was contracted to provide conceptual cost information for various mitigation options. The options they considered are:

Savannah I&D Plant

- New lime feed station, for existing 30 MGD flow.
- New lime feed station, for future 60 MGD flow.
- Granular activated carbon (GAC) to mitigate THM and THAAC problems, for existing 30 MGD flow.
- Granular activated carbon (GAC) to mitigate THM and THAAC problems, for future 60 MGD flow.
- GAC in a split flow system (50% of total flow) for existing 30 MGD flow.
- GAC in a split flow system (50% of total flow) for future 60 MGD flow.
- Ozonation to mitigate THM and THAAC problems, for existing 30 MGD flow.
- Ozonation to mitigate THM and THAAC problems, for future 60 MGD flow.

Weyerhaeuser

- New demineralizer, 1 MGD.
- RO pretreatment for demineralizer feed water, 1 MGD.
- RO pretreatment for demineralizer and pulp and fiber line feed, 8 MGD.

International Paper

- New demineralizer, 4 MGD.
- RO pretreatment for demineralizer feed water, 4 MGD.
- RO pretreatment for existing plant flows, 10 MGD.
- RO pretreatment for existing plant flows, 25 MGD.

A summary of Tetra Tech cost opinions is shown in Table 9 on the following page, and their detailed calculations are included in the Appendix.

TABLE 9
Savannah Harbor Expansion Project
Chloride Impact Assessment
Tetra Tech Summary of Cost Opinions

Description	Conceptual Cost Opinion		
	Capital Cost ($)	Amortized Capital Cost ($/year)	O&M Costs ($/year)
Savannah WTP Mitigation - New Lime Feed System Existing Flows (30 MGD)	$2,550,000	$222,000	$317,000
Savannah WTP Mitigation - New Lime Feed System Future Flows (60 MGD)	$2,820,000	$246,000	$597,000
Savannah WTP Mitigation - GAC Treatment Existing Flows (30 MGD)	$23,580,000	$2,056,000	$9,224,000
Savannah WTP Mitigation - GAC Treatment Future Flows (60 MGD)	$47,150,000	$4,111,000	$18,135,000
Savannah WTP Mitigation - GAC Split Treatment (50% of the total flow) Existing Flows (30 MGD)	$11,770,000	$1,026,000	$4,770,000
Savannah WTP Mitigation - GAC Split Treatment (50% of the total flow) Future Flows (60 MGD)	$23,580,000	$2,056,000	$9,225,000
Savannah WTP Mitigation - Ozonation Existing Flows (30 MGD)	$17,990,000	$1,568,000	$1,083,000
Savannah WTP Mitigation - Ozonation Future Flows (60 MGD)	$35,430,000	$3,089,000	$1,845,000
Weyerhaeuser Mitigation - Demineralizers (1 MGD)	$5,155,000	$449,000	$798,000
Weyerhaeuser Mitigation - RO Pretreatment for Demineralization Feed Water (1 MGD)	$4,373,000	$381,000	$629,000
Weyerhaeuser Mitigation - RO Pretreatment for Demineralization and Pulp and Fiber Line Feed (8 MGD)	$14,614,000	$1,274,000	$2,068,000
International Paper Mitigation - Demineralizers (4 MGD)	$20,618,000	$1,798,000	$3,190,000
International Paper Mitigation - RO Pretreatment for Demineralization Feed Water (4 MGD)	$10,325,000	$900,000	$1,345,000
International Paper Mitigation - RO Pretreatment for Existing Plant Flows (10 MGD)	$16,046,000	$1,399,000	$2,353,000
International Paper Mitigation - RO Pretreatment for Existing Plant Flows (25 MGD)	$30,950,000	$2,698,000	$4,970,000

REFERENCES

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14. City of Savannah Water Quality Reports for the I&D water plant on Abercorn Creek and six well water locations, January to December, 2009.
15. I&D source city water composition data, supplied by I&D plant personnel.

Documents Related to Industrial Users of Savannah I&D Water

16. Letter from Robert C. Grygotis, Weyerhaeuser VP/Mill Manager and Chris Blocker, Environmental Manager, to William Bailey, USACE: "Comments on Environmental Impact Statement for the Savannah Harbor Expansion Project", January 21, 2011.
17. Weyerhaeuser mill water flow diagram.
18. Tetra Tech: Plots of predicted chloride levels at Houlihan Bridge (Weyerhaeuser location) for various scenarios of harbor deepening, river flow and tidal flow. Provided by Hugo Rodriguez, February 22, 2011.

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19. Lin Liang and Philip Singer: "Factors Influencing the Formation and Relative Distribution of Haloacetic Acids and Trihalomethanes in Drinking Water." Environmental Science and Technology, vol. 37, 2003.
20. Email, Hugo Rodriquez to Joe Hoke et al, February 22, 2011 re. chloride levels at Houlihan Bridge.
21. Florian Mansfeld, ed: "Corrosion Mechanisms." New York: Marcel Dekker, Inc. 1987, Chapter 1.
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25. R. Winston Revie, ed: "Uhlig's Corrosion Handbook, second edition. New York: John Wily & Sons, Inc. 2000. Chapter 68, pp. 1197-1206.
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APPENDIX

THE WATSIM DATA MANAGEMENT PROGRAM

WatSim® is one of a group of four software programs developed by French Creek Software, Inc. (www.frenchcreeksoftware.com) to facilitate comparing water supplies and predicting the effects of changes in water composition and chemical treatment on corrosion and mineral scaling problems. The four programs are:

- WatSim®: Covers municipal water, including the effects of changes in water composition on maximum solubilities of copper and lead, corrosion of steel, and mineral scaling.
- WaterCycle®: Covers cycle calculations, corrosion and scaling in cooling tower water.
- HydroDose®: Covers water chemistry and scaling in reverse osmosis systems.
- DownholeSat®: Covers water chemistry in oil production operations.

Technical background

WatSim™ combines the predictive methods for copper and lead outlined in E.P.A. Drinking Water Research Division technical papers and publications, with the prediction accuracy of ion association models in the inorganic chemistry of water solutions, to provide sophisticated modeling of water composition and properties. In 1984, Pisigan & SIngley modeled steel corrosion rates based on water composition data. Their work, since modified and expanded by current understandings of corrosion mechanisms and corrosion inhibition technology, provides the basis for corrosion modeling in the WatSim program. Other papers and publications used in the development of the WatSim program are listed as references below.

The WatSim program also models the solubility of lead and copper, the scale potential for common mineral scalants over a broad operating range of water compositions. WatSim calculates empirical water treatment indices, such as the Langelier saturation index, the Ryznar stability index, and the Larson-Skold ratio among others, more accurately than can be done using common graphical and slide rule methods. WatSim provides additional information in the form of sophisticated ion association model saturation levels.

WatSim includes the ability to model and predict corrosion rates on steel as a function of water chemistry, with and without chemical adjustment. With these capabilities, WatSim can assist in establishing control limits based on pH, dissolved inorganic carbon (D.I.C) and temperature profiles. The program can help estimate acid or alkali requirements to maintain a prescribed pH control point, and it can calculate the lime feed required to achieve established control parameters.

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The following references include technology which influences the calculations used for corrosion rates of mild steel and Pb and Cu solubilities in WatSim.™

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11. Distribution System Water Quality Changes Following Corrosion Control Strategies, AWWA Research foundation, 1999.
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27. PHREEQC (Version 2)--A Computer Program for Speciation, Batch-Reaction, One-Dimensional Transport, and Inverse Geochemical Calculations, U.S. Geological Survey, 2005.
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TABLES OF WATSIM CALCULATIONS

The following 8 pages present the detailed WatSIm study printouts that contain the information used to prepare Tables 2, 3 and 4, and Figures 3 and 4 in this report.

WatSim™ Study by Arthur Freedman Associates, Inc.
WATER CHEMISTRY and DEPOSITION POTENTIAL INDICATORS VERSUS pH

Anal. #1 City of Savannah – I&D Plant – Treated Surface Water
Study Basis:
Column 1: Average Treated Water Chemistry for February 2010
Columns 2 thru 7: Added lime to raise pH, alkalinity & calcium
Finished water temperature = 12.3 C/54.1F

	1	2	3	4	5	6	7
pH	6.96	7.13	7.31	7.48	7.65	7.83	8.00
CATIONS							
Calcium (as CaCO3)	27.80	34.40	43.14	54.68	69.94	90.12	116.79
Magnesium (as CaCO3)	6.26	6.26	6.26	6.26	6.26	6.26	6.26
Sodium (as Na)	11.58	11.58	11.58	11.58	11.58	11.58	11.58
Iron (as Fe)	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Manganese (as Mn)	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Aluminum (as Al)	0.068	0.068	0.068	0.068	0.068	0.068	0.068
ANIONS							
Chloride (as Cl)	6.63	6.63	6.63	6.63	6.63	6.63	6.63
Sulfate (as SO4)	25.06	25.06	25.06	25.06	25.06	25.06	25.06
"M" Alkalinity	22.8	30.1	39.7	52.5	69.4	91.9	121.8
"P" Alkalinity	0.1	0.1	0.2	0.2	0.3	0.6	1.1
Silica(as SiO2)	4.42	4.42	4.42	4.42	4.42	4.42	4.42
Total phos.(as PO4)	0.66	0.66	0.66	0.66	0.66	0.66	0.66
Pyrophosphate(PO4)	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Orthophosphate(PO4)	0.44	0.44	0.44	0.44	0.44	0.44	0.44
STUDY PARAMETERS							
pH with Lime dosage	6.96	7.13	7.31	7.48	7.65	7.83	8.00
Lime dosage, mg/l	0.20	5.64	12.83	22.34	34.91	51.53	73.50
Calculated TDS	98.11	109.36	124.19	143.86	169.99	204.68	250.73
PREDICTED CORROSION RATE							
1010 Carbon Steel, mpy	31.62	17.93	10.05	5.57	3.05	1.65	0.888
CHEMICAL PROPERTIES							
Pb Solubility(ug/L)	77.38	39.40	20.08	10.24	5.23	2.68	1.37
Cu Solubility(mg/L)	5.00	3.23	2.31	1.80	1.49	1.29	1.15
PPO4 Solubility(mg/L)	10.04	7.65	5.84	4.49	3.48	2.72	2.15
PO4 Solubility(mg/L)	224.31	92.54	39.73	17.86	8.45	4.22	2.23
D.I.C.(mg/L C)	6.67	8.37	10.60	13.56	17.50	22.73	29.69

SATURATION LEVEL							
Calcite	0.00564	0.0136	0.0330	0.0809	0.199	0.490	1.20
Aragonite	0.00499	0.0120	0.0293	0.0717	0.176	0.434	1.07
Calcium oxalate	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Calcium phosphate	< 0.001	< 0.001	< 0.001	0.00196	0.00971	0.0444	0.187
Calcium polyphosphate	0.0373	0.0489	0.0643	0.0842	0.110	0.141	0.180
Silica	0.0527	0.0527	0.0526	0.0526	0.0526	0.0525	0.0524
Magnesium silicate	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Ferric hydroxide	0.717	1.56	3.37	7.08	14.16	25.66	39.32
SIMPLE INDICES							
Langelier	-2.31	-1.89	-1.49	-1.08	-0.685	-0.286	0.113
Ryznar	11.58	10.92	10.28	9.65	9.02	8.40	7.77
Larson-Skold	1.57	1.19	0.896	0.677	0.512	0.387	0.292

WatSim™ Study by Arthur Freedman Associates, Inc.
WATER CHEMISTRY and DEPOSITION POTENTIAL INDICATORS VERSUS pH

Anal. #2 City of Savannah – I&D Plant – Treated Surface Water w/25 ppm Cl
Study Basis:
Column 1: Average Treated Water Chemistry for Feb. 2010 w/25 ppm Cl
Columns 2 thru 7: Added lime to raise pH, alkalinity & calcium
Finished water temperature = 12.3 C/54.1F

	1	2	3	4	5	6	7
				pH			
	6.96	7.13	7.31	7.48	7.65	7.83	8.00
CATIONS							
Calcium (as CaCO3)	27.80	34.41	43.14	54.68	69.95	90.12	116.79
Magnesium (as CaCO3)	6.26	6.26	6.26	6.26	6.26	6.26	6.26
Sodium (as Na)	23.49	23.49	23.49	23.49	23.49	23.49	23.49
Iron (as Fe)	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Manganese (as Mn)	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Aluminum (as Al)	0.0680	0.0680	0.0680	0.0680	0.0680	0.0680	0.0680
ANIONS							
Chloride (as Cl)	25.00	25.00	25.00	25.00	25.00	25.00	25.00
Sulfate (as SO4)	25.06	25.06	25.06	25.06	25.06	25.06	25.06
"M" Alkalinity	22.8	30.1	39.7	52.5	69.4	91.9	121.8
"P" Alkalinity	0.1	0.1	0.2	0.2	0.3	0.6	1.1
Silica(as SiO2)	4.42	4.42	4.42	4.42	4.42	4.42	4.42
Total phos.(as PO4)	0.66	0.66	0.66	0.66	0.66	0.66	0.66
Pyrophosphate(PO4)	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Orthophosphate(PO4)	0.44	0.44	0.44	0.44	0.44	0.44	0.44
STUDY PARAMETERS							
pH with Lime dosage	6.96	7.13	7.31	7.48	7.65	7.83	8.00
Lime dosage, mg/l	0.20	5.64	12.83	22.34	34.91	51.53	73.50
Calculated TDS	128.36	139.61	154.45	174.12	200.25	234.95	281.00
PREDICTED CORROSION RATE							
1010 Carbon Steel mpy	47.47	26.95	15.13	8.40	4.61	2.50	1.34
CHEMICAL PROPERTIES							
Pb Solubility(ug/L)	77.84	39.62	20.18	10.29	5.26	2.69	1.38
Cu Solubility(mg/L)	5.11	3.28	2.35	1.83	1.51	1.31	1.16
PPO4 Solubility(mg/L)	10.52	8.00	6.10	4.67	3.61	2.81	2.22
PO4 Solubility(mg/L)	247.00	101.54	43.39	19.40	9.12	4.52	2.37
D.I.C.(mg/l C)	6.67	8.36	10.59	13.55	17.49	22.73	29.69
SATURATION LEVEL							
Calcite	0.00548	0.0132	0.0322	0.0791	0.195	0.481	1.18
Aragonite	0.00486	0.0117	0.0286	0.0701	0.173	0.426	1.05
Calcium oxalate	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Calcium phosphate	< 0.001	< 0.001	< 0.001	0.00180	0.00899	0.0415	0.176
Calcium polyphosphate	0.0343	0.0453	0.0600	0.0791	0.104	0.135	0.172
Silica	0.0527	0.0527	0.0526	0.0526	0.0526	0.0525	0.0524
Magnesium silicate	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Ferric hydroxide	0.702	1.53	3.31	6.97	13.97	25.39	39.04
SIMPLE INDICES							
Langelier	-2.33	-1.91	-1.50	-1.10	-0.695	-0.295	0.105
Ryznar	11.61	10.95	10.30	9.67	9.04	8.42	7.79
Larson-Skold	2.71	2.05	1.55	1.17	0.886	0.669	0.505
C.C.P.P.	-2.65	-2.21	-1.78	-1.34	-0.840	-0.130	1.09

WatSim^{TM} Study by Arthur Freedman Associates, Inc.
WATER CHEMISTRY and DEPOSITION POTENTIAL INDICATORS VERSUS pH

Anal. #3 City of Savannah – I&D Plant – Treated Surface Water w/50 ppm Cl
Study Basis:
Column 1: Average Treated Water Chemistry for Feb. 2010 w/50 ppm Cl
Columns 2 thru 7: Added lime to raise pH, alkalinity & calcium
Finished water temperature = 12.3 C/54.1F

	1	2	3	4	5	6	7
pH	6.96	7.13	7.31	7.48	7.65	7.83	8.00
CATIONS							
Calcium (as CaCO3)	27.80	34.41	43.14	54.68	69.95	90.12	116.79
Magnesium (as CaCO3)	6.26	6.26	6.26	6.26	6.26	6.26	6.26
Sodium (as Na)	39.70	39.70	39.70	39.70	39.70	39.70	39.70
Iron (as Fe)	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Manganese (as Mn)	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Aluminum (as Al)	0.0680	0.0680	0.0680	0.0680	0.0680	0.0680	0.0680
ANIONS							
Chloride (as Cl)	50.00	50.00	50.00	50.00	50.00	50.00	50.00
Sulfate (as SO4)	25.06	25.06	25.06	25.06	25.06	25.06	25.06
"M" Alkalinity	22.8	30.1	39.7	52.5	69.4	91.9	121.8
"P" Alkalinity	0.1	0.1	0.2	0.2	0.3	0.6	1.1
Silica(as SiO2)	4.42	4.42	4.42	4.42	4.42	4.42	4.42
Total phos.(as PO4)	0.66	0.66	0.66	0.66	0.66	0.66	0.66
Pyrophosphate(PO4)	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Orthophosphate(PO4)	0.44	0.44	0.44	0.44	0.44	0.44	0.44
STUDY PARAMETERS							
pH with Lime dosage	6.96	7.13	7.31	7.48	7.65	7.83	8.00
Lime dosage, mg/l	0.20	5.64	12.83	22.34	34.91	51.53	73.50
Calculated TDS	169.54	180.79	195.63	215.30	241.44	276.14	322.19
PREDICTED CORROSION RATE							
1010 Carbon Steel, mpy	58.38	33.19	18.66	10.37	5.70	3.10	1.67
CHEMICAL PROPERTIES							
Pb Solubility(ug/L)	78.38	39.89	20.31	10.35	5.28	2.70	1.38
Cu Solubility(mg/L)	5.23	3.36	2.39	1.86	1.54	1.32	1.18
PPO4 Solubility(mg/L)	11.12	8.44	6.42	4.91	3.78	2.94	2.31
PO4 Solubility(mg/L)	276.45	113.31	48.23	21.45	10.02	4.93	2.57
D.I.C.(mg/L C)	6.66	8.36	10.59	13.55	17.49	22.73	29.68

SATURATION LEVEL							
Calcite	0.00531	0.0128	0.0313	0.0770	0.190	0.469	1.16
Aragonite	0.00471	0.0114	0.0277	0.0682	0.168	0.416	1.03
Calcium oxalate	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Calcium phosphate	< 0.001	< 0.001	< 0.001	0.00163	0.00817	0.0380	0.163
Calcium polyphosphate	0.0310	0.0413	0.0551	0.0733	0.0968	0.127	0.163
Silica	0.0527	0.0527	0.0526	0.0526	0.0526	0.0525	0.0524
Magnesium silicate	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Ferric hydroxide	0.685	1.50	3.24	6.83	13.74	25.06	38.69
SIMPLE INDICES							
Langelier	-2.35	-1.92	-1.51	-1.11	-0.707	-0.305	0.0956
Ryznar	11.65	10.98	10.33	9.70	9.07	8.44	7.81
Larson-Skold	4.27	3.23	2.44	1.85	1.40	1.05	0.795
C.C.P.P.	-2.78	-2.32	-1.87	-1.41	-0.893	-0.169	1.06

WatSim^{TM} Study by Arthur Freedman Associates, Inc.
WATER CHEMISTRY and DEPOSITION POTENTIAL INDICATORS VERSUS pH

Anal. #4 City of Savannah – I&D Plant – Treated Surface Water w/70 ppm Cl
Study Basis:
Column 1: Average Treated Water Chemistry for Feb. 2010 w/70 ppm Cl
Columns 2 thru 7: Added lime to raise pH, alkalinity & calcium
Finished water temperature = 12.3 C/54.1F

	1	2	3	4	5	6	7
pH	6.96	7.13	7.31	7.48	7.65	7.83	8.00
CATIONS							
Calcium (as CaCO3)	27.80	34.41	43.14	54.69	69.95	90.12	116.79
Magnesium (as CaCO3)	6.26	6.26	6.26	6.26	6.26	6.26	6.26
Sodium (as Na)	52.67	52.67	52.67	52.67	52.67	52.67	52.67
Iron (as Fe)	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Manganese (as Mn)	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Aluminum (as Al)	0.068	0.068	0.068	0.068	0.068	0.068	0.068
ANIONS							
Chloride (as Cl)	70.00	70.00	70.00	70.00	70.00	70.00	70.00
Sulfate (as SO4)	25.06	25.06	25.06	25.06	25.06	25.06	25.06
"M" Alkalinity	22.8	30.1	39.7	52.5	69.4	91.9	121.8
"P" Alkalinity	0.1	0.1	0.2	0.2	0.3	0.6	1.1
Silica(as SiO2)	4.42	4.42	4.42	4.42	4.42	4.42	4.42
Total phos.(as PO4)	0.66	0.66	0.66	0.66	0.66	0.66	0.66
Pyrophosphate(PO4)	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Orthophosphate(PO4)	0.44	0.44	0.44	0.44	0.44	0.44	0.44
STUDY PARAMETERS							
pH with Lime dosage	6.96	7.13	7.31	7.48	7.65	7.83	8.00
Lime dosage, mg/l	0.20	5.64	12.83	22.34	34.91	51.53	73.50
Calculated TDS	202.49	213.74	228.57	248.25	274.39	309.09	355.14
PREDICTED CORROSION RATE							
1010 Carbon Steel, mpy	64.39	36.64	20.62	11.48	6.31	3.43	1.85
CHEMICAL PROPERTIES							
Pb Solubility(ug/L)	78.77	40.07	20.40	10.40	5.31	2.71	1.39
Cu Solubility(mg/L)	5.32	3.41	2.43	1.88	1.55	1.34	1.19
PPO4 Solubility(mg/L)	11.57	8.77	6.66	5.08	3.91	3.03	2.38
PO4 Solubility(mg/L)	299.24	122.47	52.02	23.07	10.73	5.25	2.73
D.I.C.(mg/L C)	6.66	8.35	10.58	13.55	17.49	22.72	29.68

SATURATION LEVEL							
Calcite	0.00519	0.0126	0.0307	0.0755	0.187	0.461	1.14
Aragonite	0.00460	0.0111	0.0272	0.0669	0.165	0.409	1.01
Calcium oxalate	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Calcium phosphate	< 0.001	< 0.001	< 0.001	0.00151	0.00762	0.0356	0.154
Calcium polyphosphate	0.0288	0.0386	0.0517	0.0692	0.0919	0.121	0.157
Silica	0.0527	0.0527	0.0526	0.0526	0.0526	0.0525	0.0524
Magnesium silicate	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Ferric hydroxide	0.673	1.47	3.19	6.74	13.57	24.81	38.43
SIMPLE INDICES							
Langelier	-2.36	-1.94	-1.52	-1.12	-0.715	-0.313	0.0883
Ryznar	11.68	11.00	10.35	9.72	9.08	8.45	7.82
Larson-Skold	5.52	4.17	3.16	2.39	1.80	1.36	1.03
C.C.P.P.	-2.88	-2.41	-1.94	-1.47	-0.932	-0.199	1.04

WatSim^{TM} Study by Arthur Freedman Associates, Inc.
WATER CHEMISTRY and DEPOSITION POTENTIAL INDICATORS VERSUS pH

Anal. #5 City of Savannah – I&D Plant – Treated Surface Water
Study Basis:
Column 1: Average Treated Water Chemistry for September 2010
Columns 2 thru 7: Added lime to raise pH, alkalinity & calcium
Finished water temperature = 28.3C/83F

	1	2	3	4	5	6	7
pH	7.09	7.24	7.39	7.55	7.70	7.85	8.00
CATIONS							
Calcium (as $CaCO_3$)	38.08	45.90	55.88	68.62	84.88	105.65	132.15
Magnesium (as $CaCO_3$)	9.24	9.24	9.24	9.24	9.24	9.24	9.24
Sodium (as Na)	19.07	19.07	19.07	19.07	19.07	19.07	19.07
Iron (as Fe)	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Manganese (as Mn)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aluminum (as Al)	0.024	0.024	0.024	0.024	0.024	0.024	0.024
ANIONS							
Chloride (as Cl)	11.31	11.31	11.31	11.31	11.31	11.31	11.31
Sulfate (as SO_4)	38.54	38.54	38.54	38.54	38.54	38.54	38.54
"M" Alkalinity	31.2	39.8	50.8	64.9	82.8	105.7	135.0
"P" Alkalinity	0.1	0.1	0.2	0.3	0.5	1.0	1.9
Silica(as SiO_2)	7.96	7.96	7.96	7.96	7.96	7.96	7.96
Total phos.(as PO_4)	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Pyrophosphate(PO_4)	0.31	0.31	0.31	0.31	0.31	0.31	0.31
Orthophosphate(PO_4)	0.64	0.64	0.64	0.64	0.64	0.64	0.64
STUDY PARAMETERS							
pH with Lime dosage	7.09	7.24	7.39	7.55	7.70	7.85	8.00
Lime dosage, mg/l	0.21	6.65	14.87	25.36	38.76	55.86	77.70
Calculated TDS	145.11	158.00	174.70	196.21	223.78	258.98	303.69
PREDICTED CORROSION RATE							
1010 Carbon Steel, MPY	73.59	44.38	26.52	15.70	9.22	5.38	3.12
CHEMICAL PROPERTIES							
Pb Solubility(ug/L)	35.69	19.09	10.22	5.48	2.94	1.58	0.855
Cu Solubility(mg/L)	1.12	0.867	0.711	0.607	0.534	0.480	0.440
PPO4 Solubility(mg/L)	9.03	7.08	5.56	4.38	3.48	2.79	2.26
PO4 Solubility(mg/L)	64.39	31.42	15.87	8.33	4.56	2.62	1.58
D.I.C.(mg/L C)	8.79	10.71	13.21	16.44	20.59	25.87	32.59
SATURATION LEVEL							
Calcite	0.0256	0.0551	0.119	0.259	0.564	1.22	2.64
Aragonite	0.0222	0.0478	0.103	0.225	0.489	1.06	2.29
Calcium oxalate	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Calcium phosphate	< 0.001	0.00272	0.0114	0.0452	0.168	0.588	1.92
Calcium polyphosphate	0.0524	0.0673	0.0865	0.111	0.141	0.178	0.223
Silica	0.0624	0.0624	0.0623	0.0622	0.0621	0.0619	0.0616
Magnesium silicate	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Ferric hydroxide	0.940	1.85	3.59	6.79	12.29	20.51	30.11
SIMPLE INDICES							
Langelier	-1.59	-1.24	-0.900	-0.554	-0.209	0.136	0.482
Ryznar	10.27	9.73	9.19	8.65	8.12	7.58	7.04
Larson-Skold	1.80	1.41	1.11	0.866	0.678	0.531	0.416
C.C.P.P.	-1.51	-1.22	-0.890	-0.477	0.134	1.16	3.05

WatSim™ Study by Arthur Freedman Associates, Inc.
WATER CHEMISTRY and DEPOSITION POTENTIAL INDICATORS VERSUS pH

Anal. #6 City of Savannah – I&D Plant – Treated Surface Water w/25 ppm Cl
Study Basis:
Column 1: Average Treated Water Chemistry for Sept. 2010 w/25 ppm Cl
Columns 2 thru 7: Added lime to raise pH, alkalinity & calcium
Finished water temperature = 28.3C/83F

	1	2	3	4	5	6	7
	pH						
	7.09	7.24	7.39	7.55	7.70	7.85	8.00
CATIONS							
Calcium (as CaCO3)	38.08	45.90	55.88	68.62	84.88	105.65	132.15
Magnesium (as CaCO3)	9.24	9.24	9.24	9.24	9.24	9.24	9.24
Sodium (as Na)	27.95	27.95	27.95	27.95	27.95	27.95	27.95
Iron (as Fe)	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Manganese (as Mn)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aluminum (as Al)	0.024	0.024	0.024	0.024	0.024	0.024	0.024
ANIONS							
Chloride (as Cl)	25.00	25.00	25.00	25.00	25.00	25.00	25.00
Sulfate (as SO4)	38.54	38.54	38.54	38.54	38.54	38.54	38.54
"M" Alkalinity	31.2	39.9	51.0	65.1	83.3	106.7	136.8
"P" Alkalinity	0.1	0.1	0.2	0.3	0.6	1.0	1.9
Silica(as SiO2)	7.96	7.96	7.96	7.96	7.96	7.96	7.96
Total phos.(as PO4)	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Pyrophosphate(PO4)	0.31	0.31	0.31	0.31	0.31	0.31	0.31
Orthophosphate(PO4)	0.64	0.64	0.64	0.64	0.64	0.64	0.64
STUDY PARAMETERS							
pH with Lime dosage	7.09	7.24	7.39	7.55	7.70	7.85	8.00
Lime dosage, mg/l	0.21	6.65	14.87	25.36	38.76	55.86	77.70
Calculated TDS	166.7	180.0	197.0	218.8	246.7	282.5	328.4
PREDICTED CORROSION RATE							
1010 Carbon Steel, mpy	93.69	56.54	33.79	20.00	11.74	6.83	3.95
CHEMICAL PROPERTIES							
Pb Solubility(ug/L)	35.75	19.12	10.23	5.48	2.94	1.58	0.848
Cu Solubility(mg/L)	1.13	0.878	0.720	0.615	0.542	0.488	0.449
PPO4 Solubility(mg/L)	9.30	7.28	5.71	4.50	3.57	2.86	2.32
PO4 Solubility(mg/L)	68.47	33.35	16.81	8.80	4.80	2.74	1.65
D.I.C.(mg/L C)	8.59	10.59	13.15	16.44	20.66	26.07	33.00
SATURATION LEVEL							
Calcite	0.0252	0.0543	0.118	0.256	0.559	1.22	2.65
Aragonite	0.0219	0.0471	0.102	0.222	0.485	1.06	2.30
Calcium oxalate	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Calcium phosphate	< 0.001	0.00257	0.0108	0.0429	0.160	0.562	1.84
Calcium polyphosphate	0.0493	0.0636	0.0822	0.106	0.135	0.172	0.215
Silica	0.0624	0.0624	0.0623	0.0622	0.0621	0.0619	0.0616
Magnesium silicate	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Ferric hydroxide	0.928	1.83	3.55	6.72	12.18	20.36	29.96
SIMPLE INDICES							
Langelier	-1.60	-1.25	-0.906	-0.560	-0.213	0.134	0.481
Ryznar	10.29	9.75	9.21	8.66	8.12	7.58	7.04
Larson-Skold	2.42	1.89	1.48	1.16	0.907	0.708	0.552
C.C.P.P.	-1.55	-1.25	-0.919	-0.498	0.122	1.17	3.08

WatSim™ Study by Arthur Freedman Associates, Inc.
WATER CHEMISTRY and DEPOSITION POTENTIAL INDICATORS VERSUS pH

Anal. #7 City of Savannah – I&D Plant – Treated Surface Water w/50 ppm Cl
Study Basis:
Column 1: Average Treated Water Chemistry for Sept. 2010 w/50 ppm Cl
Columns 2 thru 7: Added lime to raise pH, alkalinity & calcium
Finished water temperature = 28.3C/83F

	1	2	3	4	5	6	7
pH	7.09	7.24	7.39	7.55	7.70	7.85	8.00
CATIONS							
Calcium (as CaCO3)	38.08	45.90	55.88	68.62	84.89	105.65	132.15
Magnesium (as CaCO3)	9.24	9.24	9.24	9.24	9.24	9.24	9.24
Sodium (as Na)	44.16	44.16	44.16	44.16	44.16	44.16	44.16
Iron (as Fe)	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Manganese (as Mn)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aluminum (as Al)	0.024	0.024	0.024	0.024	0.024	0.024	0.024
ANIONS							
Chloride (as Cl)	50.00	50.00	50.00	50.00	50.00	50.00	50.00
Sulfate (as SO4)	38.54	38.54	38.54	38.54	38.54	38.54	38.54
"M" Alkalinity	31.2	39.9	51.0	65.1	83.3	106.7	136.8
"P" Alkalinity	0.1	0.1	0.2	0.3	0.6	1.0	1.9
Silica(as SiO2)	7.96	7.96	7.96	7.96	7.96	7.96	7.96
Total phos.(as PO4)	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Pyrophosphate(PO4)	0.31	0.31	0.31	0.31	0.31	0.31	0.31
Orthophosphate(PO4)	0.64	0.64	0.64	0.64	0.64	0.64	0.64
STUDY PARAMETERS							
pH with Lime dosage	7.09	7.24	7.39	7.55	7.70	7.85	8.00
Lime dosage, mg/l	0.21	6.65	14.87	25.36	38.76	55.86	77.70
Calculated TDS	207.85	221.13	238.15	259.96	287.92	323.73	369.58
PREDICTED CORROSION RATE							
1010 Carbon Steel, mpy	115.3	69.67	41.70	24.72	14.52	8.47	4.90
CHEMICAL PROPERTIES							
Pb Solubility(ug/L)	35.90	19.19	10.27	5.50	2.95	1.58	0.851
Cu Solubility(mg/L)	1.16	0.894	0.732	0.625	0.549	0.494	0.455
PPO4 Solubility(mg/L)	9.78	7.64	5.98	4.70	3.72	2.97	2.40
PO4 Solubility(mg/L)	75.74	36.79	18.48	9.63	5.23	2.97	1.78
D.I.C.(mg/L C)	8.59	10.59	13.15	16.44	20.66	26.07	33.00
SATURATION LEVEL							
Calcite	0.0245	0.0529	0.115	0.250	0.547	1.19	2.60
Aragonite	0.0213	0.0459	0.0995	0.217	0.474	1.04	2.25
Calcium oxalate	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Calcium phosphate	< 0.001	0.00234	0.00999	0.0393	0.148	0.522	1.72
Calcium polyphosphate	0.0446	0.0579	0.0753	0.0976	0.126	0.161	0.202
Silica	0.0625	0.0624	0.0623	0.0622	0.0621	0.0619	0.0616
Magnesium silicate	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Ferric hydroxide	0.908	1.79	3.48	6.61	12.00	20.12	29.70
SIMPLE INDICES							
Langelier	-1.62	-1.27	-0.919	-0.572	-0.224	0.124	0.472
Ryznar	10.32	9.77	9.23	8.69	8.15	7.60	7.06
Larson-Skold	3.55	2.78	2.18	1.70	1.33	1.04	0.81
C.C.P.P.	-1.63	-1.31	-0.97	-0.54	0.09	1.14	3.06

WatSim^{TM} Study by Arthur Freedman Associates, Inc.
WATER CHEMISTRY and DEPOSITION POTENTIAL INDICATORS VERSUS pH

Anal. #8 City of Savannah – I&D Plant – Treated Surface Water w/70 ppm Cl
Study Basis:
Column 1: Average Treated Water Chemistry for Sept. 2010 w/70 ppm Cl
Columns 2 thru 7: Added lime to raise pH, alkalinity & calcium
Finished water temperature = 28.3C/83F

	1	2	3	4	5	6	7
	pH						
	7.09	7.24	7.39	7.55	7.70	7.85	8.00
CATIONS							
Calcium (as CaCO3)	38.09	45.90	55.88	68.62	84.89	105.65	132.16
Magnesium (as CaCO3)	9.24	9.24	9.24	9.24	9.24	9.24	9.24
Sodium (as Na)	57.13	57.13	57.13	57.13	57.13	57.13	57.13
Iron (as Fe)	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Manganese (as Mn)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aluminum (as Al)	0.024	0.024	0.024	0.024	0.024	0.024	0.024
ANIONS							
Chloride (as Cl)	70.00	70.00	70.00	70.00	70.00	70.00	70.00
Sulfate (as SO4)	38.54	38.54	38.54	38.54	38.54	38.54	38.50
"M" Alkalinity	31.2	39.9	51.0	65.1	83.3	106.7	136.8
"P" Alkalinity	0.1	0.1	0.2	0.3	0.6	1.0	1.9
Silica(as SiO2)	7.96	7.96	7.96	7.96	7.96	7.96	7.96
Total phos.(as PO4)	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Pyrophosphate(PO4)	0.31	0.31	0.31	0.31	0.31	0.31	0.31
Orthophosphate(PO4)	0.64	0.64	0.64	0.64	0.64	0.64	0.64
STUDY PARAMETERS							
pH with Lime dosage	7.09	7.24	7.39	7.55	7.70	7.85	8.00
Lime dosage, mg/l	0.21	6.65	14.87	25.37	38.76	55.87	77.70
Calculated TDS	240.80	254.08	271.10	292.91	320.87	356.69	402.54
PREDICTED CORROSION RATE							
1010 Carbon Steel, mpy	127.2	76.94	46.09	27.35	16.09	9.39	5.44
CHEMICAL PROPERTIES							
Pb Solubility(ug/L)	36.01	19.25	10.30	5.51	2.95	1.59	0.852
Cu Solubility(mg/L)	1.17	0.906	0.741	0.632	0.555	0.499	0.459
PPO4 Solubility(mg/L)	10.14	7.92	6.19	4.86	3.84	3.06	2.47
PO4 Solubility(mg/L)	81.44	39.50	19.80	10.29	5.57	3.15	1.88
D.I.C.(mg/L C)	8.58	10.58	13.15	16.43	20.65	26.07	33.00
SATURATION LEVEL							
Calcite	0.0240	0.0519	0.113	0.246	0.538	1.18	2.56
Aragonite	0.0209	0.0450	0.0977	0.213	0.467	1.02	2.22
Calcium oxalate	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Calcium phosphate	< 0.001	0.00218	0.00922	0.0369	0.139	0.493	1.64
Calcium polyphosphate	0.0414	0.0540	0.0705	0.0919	0.119	0.153	0.193
Silica	0.0625	0.0624	0.0623	0.0622	0.0621	0.0619	0.0616
Magnesium silicate	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Ferric hydroxide	0.894	1.76	3.43	6.53	11.87	19.94	29.50
SIMPLE INDICES							
Langelier	-1.63	-1.28	-0.928	-0.580	-0.232	0.116	0.465
Ryznar	10.34	9.79	9.25	8.71	8.16	7.62	7.07
Larson-Skold	4.45	3.49	2.73	2.14	1.67	1.30	1.02
C.C.P.P.	-1.68	-1.36	-1.01	-0.57	0.070	1.13	3.05

RÉSUMÉS

ARTHUR J. FREEDMAN, Ph.D.

PRESENT RESPONSIBILITIES:

As President of Arthur Freedman Associates, Inc., Dr. Freedman specializes in all aspects of the treatment and operation of water preparation, cooling water, boiler water, process water and wastewater systems. Dr. Freedman provides technical and economic consultation, including problem solving, failure analyses, surveillance and audit services, expert witness services, conceptual design capabilities and marketing services. His clients include both the water treatment industry and water-using industrial plants, nuclear and fossil fueled power generation stations, waste water treatment plants and commercial facilities. Dr. Freedman has been providing water treatment consulting services since 1981. He has a total of 46 years of experience in the water treatment industry.

PERTINENT EXPERIENCE:

Dr. Freedman's diversified experience in water management includes:

- Specific problem solving and failure analyses involving water preparation, potable water, cooling water, boiler water, process water and waste water systems in power stations, manufacturing plants, other process industries and commercial, municipal and residential facilities.
- Water system performance audits and technical supervision for nuclear and fossil fueled electric power plants and commercial facilities.
- Preparation of cooling and boiler water treatment specifications, evaluation of alternative chemical treatment programs, selection of water treatment vendors, and water management audit functions for industrial and commercial facilities.
- Expert witness services in matters involving commercial and industrial water systems.

Following are some of Dr. Freedman's specific technical accomplishments:

- Developed widely used methods for evaluating and controlling microbiologically-influenced corrosion in industrial plants, electric power stations and commercial facilities.
- Investigated numerous water-related failures in commercial and residential buildings and campus facilities, recommended remediation technology and ongoing water treatment and operating procedures.
- Developed startup and ongoing water treatment procedures for newly constructed high-rise commercial facilities.
- Studied effects of water composition and water treatment on common metalliuc and nonmetallic materials of construction, and recommended treatment programs for various combinations of these materials.
- Evaluated alternative macrofouling control methods and selected specific zebra mussel control procedures for power generating stations. Prepared a comprehensive zebra mussel control plan and operating manual for a multistation nuclear power generating authority.
- Investigated numerous specific water-related scale, corrosion and microbiological problems involving metals, concrete, plastic materials and coatings in refineries, petrochemical plants and power stations.
- Developed some of the first non-chromate polymer-based corrosion control programs that were successfully applied in the refining industry. These programs are still in active use.
- Developed new and unique refinery process side corrosion inhibitors, antifouling additives, pour point depressants and dispersants.
- Developed polymer applications for settling and water clarification in the phosphate mining industry.
- Designed and operated laboratory, pilot-scale and on-line cooling and boiler water test facilities.
- Pilot-tested a chemical treatment program for use in a new power station cooling system using secondary sewage effluent as makeup, and supervised the successful startup and operation of this system.

- Based on this success, designed the treatment system for a mile-long pipeline to carry treated secondary effluent to a new power station cooling system.
- Designed the treatment system for a pipeline carrying treated secondary effluent to a university central power plant for use as cooling tower makeup.
- Computer programs: Developed and implemented programs to measure heat transfer and corrosion rates on-line in operating cooling water systems, and to control boiler house operations. These programs include chemical inventory control and evaluation of analytical data and operating parameters.
- Planned and directed major research programs associated with cooling water and boiler water treatment chemicals.
- Pioneered the development of non-chromate, alkaline cooling water treatment technology for industrial and commercial applications, including the current most widely-used product lines.
- Helped to develop and commercialize the Corrater® and Corrosometer® for on-line measurements of corrosion rates.
- Optimized wastewater plant operations in paper mills, refineries and municipal treatment plants. This work included polymer evaluations and recommendations for changes in plant operating procedures to improve throughput and efficiency.
- Designed and supervised construction of new cooling and boiler water laboratories and pilot facilities.
- Wrote comprehensive general and site-specific technical water treatment manuals, and presented many technical and marketing training programs covering all aspects of industrial and commercial cooling and boiler water treatment.
- Identified new product needs and provided technical and marketing data required for the development of new water treatment products.
- Participated in many industry, government and professional groups dealing with water chemistry, corrosion and environmental problems.

EDUCATION:

B.S. 1945 - New York University - Summa cum laude, chemistry.
M.S. 1946 - New York University - Physical chemistry.
Ph.D. 1948 - New York University - Cum laude, inorganic chemistry.

PREVIOUS POSITIONS:

- From 1981 to the present, Dr. Freedman has served as President and Principal Consultant with Arthur Freedman Associates, Inc., working on a wide variety of water preparation, cooling water, boiler water and potable water projects in refineries, chemical plants, electric power stations, industrial plants and commercial and residential HVAC systems.
- From July, 1988 through June, 1995, Arthur Freedman Associates, Inc. provided its consulting services through Thomas M. Laronge, Inc., where Dr. Freedman served as Executive Vice President.
- From 1959 to 1981, Dr. Freedman worked for Nalco Chemical Company, where he served at various times as Group Leader and Technical Director in their cooling water, boiler water and waste water treatment laboratories, and as Marketing Manager for cooling water and water preparation chemicals. While at Nalco, Dr. Freedman was instrumental in the development of new alkaline and all-organic scale and corrosion control technology now widely used in the industry.
- Dr. Freedman was employed by the Standard Oil Company of Indiana (Amoco) from 1954 to 1959. As Senior Project Supervisor, he was responsible for the development of water and process side scaling and corrosion test instrumentation. During this time, Dr. Freedman and others developed the Corrosometer®, a device for measuring on-line corrosion rates by the change in electrical resistance of a specimen, and the Corrater®, a device that measures on-line corrosion rates in water systems by an empirical polarization resistance technique.
- From 1948 to 1954, Dr. Freedman served as a Research Associate at the University of New Mexico, the Los Alamos Scientific Laboratory, and the Massachusetts Institute of Technology. His work during this period involved analytical applications of radiochemistry.

PROFESSIONAL AFFILIATIONS AND HONORS:

- Active 50 year member of the American Chemical Society (ACS).
- Active 50 year member of NACE International (The National Association of Corrosion Engineers.)
- Ray Baum Award for Service to the Water Treatment Industry, presented by the Association of Water Technologies, awarded at the National Conference, Honolulu, Hawaii, November, 2000
- Distinguished Service Award, presented by NACE International, awarded at the National Conference, San Antonio, Texas, April 1999.
- Member, Editorial Advisory Board, Materials Performance.
- Chairman of NACE Group Committee STG-11 (Corrosion in Water Systems) 2003 - 2005.
- Chairman, NACE Committee T-7 (Corrosion by Water), 1994-1997.
- Chairman, NACE Symposium on Cooling Water Technology, 1983.
- Chairman, NACE Symposium on Microbiologically Influenced Corrosion (MIC), 1984 and 1993.
- Chairman, NACE Symposium on Ozone in Cooling Water, 1992.
- Chairman, NACE Symposium on Water Problems in Commercial Buildings, 1998 and 2002.
- Chairman of NACE Unit Committee T-7A covering cooling water corrosion, scaling and microbiological problems in commercial and industrial facilities, 1997-1999.
- Active member of current NACE Unit Committees on boiler water treatment, scale control and corrosion control instrumentation.
- Official NACE representative to an international ad hoc committee to evaluate European proposed standard methods for evaluating the performance of cooling water formulations. Chairman of NACE Task Group T-7A-22 covering this same topic.
- Presented the 50th anniversary lecture on Microbiologically-Influenced Corrosion at the NACE national meeting in 1993.

- Chairman, NACE Symposium on New Developments in Cooling Water Treatment, 2008.
- Chairman, IWC Symposium on Use of Recycled Water in Cooling Towers, 2009.

PUBLICATIONS AND PATENTS:

- Five patents, covering water and process-side corrosion inhibitors, on-line corrosion measurement techniques and zebra mussel control.
- Editor and principal author of "Technical Reference and Training Manual", a reference publication of the Association of Water Technologies (AWT), Washington, D.C., 2001 and 2007.
- Editor and principal author of "Heat Exchanger Design and Operations from the Water Treatment Viewpoint", a reference publication of the Materials Technology Institute (MTI), St. Louis, MO, 2002.
- Chapter on water treatment in commercial facilities, in "Facility Manager's Operation and Maintenance Handbook", published by McGraw-Hill, January 1999.
- Chapter on cooling water treatment, in "Process Industries Corrosion: Theory and Practice", published by NACE, 1986.
- Approximately fifty technical publications covering:
  - ◊ Solubilities of selected inorganic compounds in tertiary mixtures.
  - ◊ Fundamental aspects of cooling water and boiler water chemistry.
  - ◊ Cooling and boiler water treatment, operations and control.
  - ◊ Water treatment specifications and program implementation.
  - ◊ Development of new cooling and boiler water additives.
  - ◊ Water systems management.
  - ◊ Water system problem solving and remediation in commercial high rise and campus facilities.
  - ◊ Design of cooling and boiler water monitoring and control equipment.

  - ◊ Petroleum and petrochemical process side corrosion control.
  - ◊ Waste water management.
- Many specialized marketing studies, training programs and manuals, covering various aspects of water chemistry, cooling and boiler water treatment, corrosion control, zebra mussel control, HVAC technology and related topics.

JACK SOOST, CWT

Present Responsibilities

As a Principal Consultant with Arthur Freedman Associates, Inc., Mr. Soost provides professional services for trouble shooting cooling and boiler water applications and treatment problems, facilities water management studies and permitting, and management plans for potable water, process waters, cooling and heating systems, steam generation, wastewater treatment and reuse, and wastewater disposal. He has over 42 years experience in the water treatment and environmental engineering fields providing the background needed to conduct a wide range of problem solving, economic analysis, treatment program monitoring and supervision, conceptual design and regulatory compliance for commercial, industrial, municipal and engineering clients.

Pertinent Experience

Mr. Soost's diversified experience with water treatment processes and application of specialty chemicals for effective operation of utility systems in commercial, industrial and municipal facilities includes:

- Sales and field service of specialty chemicals for operation of potable and process water supplies, cooling and heating systems, steam generation and wastewater systems in commercial and industrial facilities. Service activities included monitoring of customers' systems, operator training, problem identification, and problem solving.

- In-depth facility surveys of water systems from inlet to outlet, laboratory and pilot scale treatability and water reuse studies, economic assessments of treatment alternatives, and water management plans to maintain cost effective facility operations while maintaining environmental regulatory compliance. Studies and plans were developed for a wide range of commercial buildings and industrial facilities including chemical, refining, steel, utility, mining, textile, meat processing, food preparation, metal finishing, automotive, and general manufacturing plants of almost all types.

- Specialty water treatment chemical formulations for potable water, cooling and heating systems, air washers, process waters, and steam generation. Marketing and application of these formulations, over 30 different biocide chemistries, and an extensive line of coagulation and flocculation polymers for waste treatment.

Education and Professional Certification

- B.S. 1962 - The Pennsylvania State University - Chemical Engineering
- Certified Water Technologist; Certificate No. 1-0042, Association of Water Technologies.

Previous Positions

- From 1988 through 2005. Mr. Soost worked for Eastern Technologies, Inc., a manufacturer of specialty chemical formulations for a wide range of water, wastewater, and fuel treatment applications.
    - From 1998 through 2005, Mr. Soost was Vice President of Marketing & Engineering. In this position, he was responsible for developing new ETI partner companies, and for maintenance and development of ETI's chemical product lines, literature and support documents. He provided ETI distributors and their end-use customers with technical and product application guidance for effective treatment performance and compliance with applicable OSHA and EPA regulations including State NPDES and local POTW permits.
    - From 1989 to 1998 Mr. Soost was Technical Director at ETI, and in this position, his responsibilities and duties included:
        - Management of all water treatment chemical product lines, evaluation of product performance, and preparation of product literature, product technical application documents, and water treatment industry training documents.
        - Supervision of compliance with applicable regulatory agency requirements including OSHA, EPA, ANSI/NSF, FDA, USDA, and State pesticide laws.
        - Technical assistance to optimize water supply, potable water, commercial/industrial water treatment and waste treatment programs.
        - Assistance to end-use customers with water treatment program performance and compliance with applicable OSHA and EPA regulations including State NPDES and local POTW permits.
- From 1982 through 1988, Mr. Soost worked for Scholler, Inc., a manufacturer and supplier of textile processing chemicals and commercial/industrial water treatment specialties and services. As Regional Sales Manager, and later as Vice President,

  Water Treatment Services, Mr. Soost was responsible for sales, technical and business management of the water treatment division.

- In 1968, Mr. Soost joined the Consulting Services Division of Betz Laboratories, Inc. as a Project Engineer responsible for process engineering and operational consulting on water supply, process and utility waters, waste disposal and process water reuse projects. This division became known as Betz Environmental Engineers, and then as BCM Engineers. Mr. Soost became Regional Sales Manager and later Assistant Vice President, responsible for marketing and managing professional environmental testing and engineering services to industrial clients.

- From 1963 to 1968, Mr. Soost was with Calgon Corporation, as a Field Service Engineer for boiler, cooling, and potable water treatment programs, and then an Assistant Project Engineer in their Process and Wastewater Consulting Services Division.

- From 1962 to 1963, Mr. Soost was in a production management training program with US Steel Corporation, Clairton Works.

Publications:

- Chemical and Physical Treatments to Remove Oil Below 50 mg/L: Concepts and Experiences. Technical Paper initially presented to American Society of Lubrication Engineers, May 1972.

- The Use of Glutaraldehyde/DBNPA Combination Treatment Program for Effective Control of Microbial Growth in Cooling Water Systems. Paper presented at NACE International, Corrosion 2002, by G. A. Ganzer, M. Freid, and J. Summerfield of The Dow Chemical Company and J. Soost and G. Reggiani of Eastern Technologies, Inc.

Professional Affiliations:

- NACE International (formerly National Association of Corrosion Engineers), Member since 1985.

- American Water Works Association (AWWA), Member since 1985.

- Association of Water Technologies (AWT) and currently serving as Chairman of Cooling Water Technical Committee. Member since 1985.

- American Chemical Society (ACS). Member since 1990.

- Cooling Tower Institute (CTI). Member 1988 to 1995.

- American Association of Textile Chemists and Colorists (AATCC). Member 1983 to October 2003. Community Service:

- East Cocalico Township Water and Sewer Authority, Former Vice Chairman and 12 year Board Member - February 1993 thru December 2005.

- The Pennsylvania Academy of Music, Lancaster, PA - Board of Trustees July 2003 to present.

- Lions Club of East Cocalico, Reamstown, PA. Member since 1995

- Denver-Adamstown Rotary Club. Founding Member 1990 to 1995.

- Doylestown Family YMCA - Board of Directors January 1983 to December 1988

BOB CUNNINGHAM, P.E.

Education

- B. S. Chemistry, the University of Pittsburgh, 1966
- M.B.A., the University of Pittsburgh, 1972
- Post-graduate work in Chemistry, The University of Pittsburgh
- Post-graduate work in Business Administration, George Washington University

Experience

40 years domestic and international field service and staff trouble shooting experience with several major national water treatment companies, involving boiler and cooling water, chemical cleaning, waste water treatment, process chemical treatment, paper chemicals treatment, oil production chemicals, and municipal water preparation .

- **Chevron, El Segundo Refinery, Isomax Division:**
    - 1982-1994, designed and serviced the water treatment program for the Isomax waste heat boilers and cooling system. Corrected problems left by previous vendor and resolved issues caused by flow-assisted corrosion, fatigue corrosion and related issues.
- **Other refinery & petrochemical systems:**
    - Metallurgy, materials selection and equipment design problems.
    - Problems exaggerated due to process contamination.
    - Waste water treatment systems, including API separators, DAF systems, IAF systems, and biological treatment plants.
    - Recovery of waste water as cooling tower make up.
- **Electric utility steam systems:**
    - Economizer, boiler, and super heater deposit and corrosion problems.
    - Unusual condensate corrosion problems.
    - Steam purity problems.
    - Velocity and multiple phase flow-accelerated corrosion phenomena.
- **Iron, steel, & basic metals systems:** Work included low flow, high heat flux applications, blast furnace and continuous caster systems.
- **HVAC systems in commercial and institutional buildings:**
    - Corrosion, deposition, and biological problems.
    - Issues involving improper equipment design and materials selection.
- **Oil production systems, including steam floods:**
    - Dissolved air flotation systems.
    - Clarification and filtration processes.
    - Boiler feedwater preparation.
    - Cooling and wastewater applications.
- **Food processing:** Projects involved boiler, cooling and wastewater processing.

- **Litigation and legislative support in all industries.**

Work History

- Currently Vice President, Arthur Freedman Associates, Trinity Center, CA
- President and Chairman, Chemisis, Inc., Mission Viejo, & Trinity Center, CA
- *Vice President, Industrial Group, Aqua Serv Engineers, Los Angeles, CA
- Vice President, Marketing & Sales Zimmite Corporation, Cleveland, OH
- Chemicals Marketing Manager, Baltimore Aircoil Co., Jessup, MD
- R&D Group Manager, Corrosion Inhibitors, Calgon Corporation, Pittsburgh, PA
- District Manager (Arco Performance & Betz Entec) and Area Mgr (Betz Entec & Olin)
- District Representative (Betz Entec & Olin)
- Product Manager, Cooling Water Treatment Chemicals, Calgon Corporation, Pittsburgh, PA
- Assistant Product Manager, Boiler Water Treatment Chemicals, Calgon Corporation, Pittsburgh, PA
- Laboratory Technician, Pittsburgh Plate Glass Co., Springdale, PA

Certifications

- California Registered Professional Corrosion Engineer
- Certified Corrosion Specialist, The National Association of Corrosion Engineers

Professional Societies

- Cooling Tower Institute, formerly President, Vice President, Chairman of the Water Treatment Committee and member of Board of Directors.
- Association of Water Technologies, former member of Board of Directors.
- National Association of Corrosion Engineers (NACE), formerly Vice Chairman, Chairman-Elect of Committee T-7A, Corrosion by Cooling Water, and National Symposium Chairman.
- International Water Conference, Advisory Board, recipient of the IWC Award of Merit, 2001.
- ASME, member of Thermal Research Committee, Sub-Committee on Industrial Boiler Chemistry.
- AISE, member.

Other

Former consultant to United States Environmental Protection Agency

TETRA TECH

Conceptual Cost Opinions

Savannah Harbor Expansion Project
Chloride Impact Assessment
Savannah WTP Mitigation Alternative
New Lime Feed System
Conceptual Opinion of Probable Cost

CAPITAL COSTS

Description		30 MGD	60 MGD
Lime Storage and Feed System		$1,350,000	$1,500,000
Electrical and Instrumentation (12% of Subtotal)		$160,000	$180,000
Paving, Grading, Drainage, & Site work (10% of Subtotal)		$140,000	$150,000
Yard Piping (10% of Subtotal)		$140,000	$150,000
Capital Cost Subtotal		*$1,790,000*	*$1,980,000*
Mob/Gen Req:	7%	$130,000	$140,000
Engineering:	15%	$270,000	$300,000
Contingency:	20%	$360,000	$400,000
Total Capital Cost		**$2,550,000**	**$2,820,000**
Total Amortized Capital Cost ($/year)[1]		**$222,000**	**$246,000**

OPERATION AND MAINTENANCE COSTS

Description	30 MGD	60 MGD
Lime Usage[2]	$274,000	$548,000
Power[3]	$7,000	$9,000
Maintenance[4]	$36,000	$40,000
Total Operation and Maintenance Cost	**$317,000**	**$597,000**

Notes and Assumptions:

1. Based on 20 years @ 6%.
2. Based on 15 mg/L and $0.18/lb.
3. Based on $0.1/kwhr.
4. Based on 2% of total WTP cost.
5. Assumes no additional operators are required.
6. Assumes adequate space is available on-site for new equipment.
7. Assumes a new lime storage and feed system is required as capacity of existing system is unknown.

Savannah Harbor Expansion Project
Chloride Impact Assessment
Savannah WTP Mitigation Alternative
GAC Treatment
Conceptual Opinion of Probable Cost

CAPITAL COSTS

Description		**30 MGD**	**60 MGD**
GAC System		$12,580,000	$25,150,000
Electrical and Instrumentation (12% of Subtotal)		$1,510,000	$3,020,000
Paving, Grading, Drainage, & Site work (10% of Subtotal)		$1,260,000	$2,520,000
Yard Piping (10% of Subtotal)		$1,260,000	$2,520,000
Capital Cost Subtotal		*$16,610,000*	*$33,210,000*
Mob/Gen Req:	7%	$1,160,000	$2,320,000
Engineering:	15%	$2,490,000	$4,980,000
Contingency:	20%	$3,320,000	$6,640,000
Total Capital Cost		**$23,580,000**	**$47,150,000**
Total Amortized Capital Cost ($/year)[1]		**$2,056,000**	**$4,111,000**

OPERATION AND MAINTENANCE COSTS

Description	**30 MGD**	**60 MGD**
GAC Regeneration[2]	$8,577,000	$17,155,000
Power[3]	$8,000	$9,000
Labor[4]	$307,000	$307,000
Maintenance[5]	$332,000	$664,000
Total Operation and Maintenance Cost	**$9,224,000**	**$18,135,000**

Notes and Assumptions:

1. Based on 20 years @ 6%.
2. Based on assumed removal of 50% of finished water TOC, an average TOC of 2.5 mg/L, an average carbon usage rate of 20 mg TOC/mg of GAC, and a regeneration cost of $1.50/lb of GAC.
3. Based on $0.1/kwhr.
4. Based on 1 additional operator per shift and $35/hr.
5. Based on 2% of total WTP cost.
6. Assumes adequate space is available on-site for new equipment.
7. Does not include the costs for additional lime treatment, which was summarized in a separate table.

Savannah Harbor Expansion Project
Chloride Impact Assessment
Savannah WTP Mitigation Alternative
GAC Split Treatment (50%)
Conceptual Opinion of Probable Cost

CAPITAL COSTS

Description		**30 MGD**	**60 MGD**
GAC System		$6,280,000	$12,580,000
Electrical and Instrumentation (12% of Subtotal)		$750,000	$1,510,000
Paving, Grading, Drainage, & Site work (10% of Subtotal)		$630,000	$1,260,000
Yard Piping (10% of Subtotal)		$630,000	$1,260,000
Capital Cost Subtotal		*$8,290,000*	*$16,610,000*
Mob/Gen Req:	7%	$580,000	$1,160,000
Engineering:	15%	$1,240,000	$2,490,000
Contingency:	20%	$1,660,000	$3,320,000
Total Capital Cost		**$11,770,000**	**$23,580,000**
Total Amortized Capital Cost ($/year)[1]		**$1,026,000**	**$2,056,000**

OPERATION AND MAINTENANCE COSTS

Description	**30 MGD**	**60 MGD**
GAC Regeneration[2]	$4,289,000	$8,577,000
Power[3]	$8,000	$9,000
Labor[4]	$307,000	$307,000
Maintenance[5]	$166,000	$332,000
Total Operation and Maintenance Cost	**$4,770,000**	**$9,225,000**

Notes and Assumptions:

1. Based on 20 years @ 6%.
2. Based on treating 50% of the flow with GAC and an assumed removal of 50% of finished water TOC, an average TOC of 2.5 mg/L, an average carbon usage rate of 20 mg TOC/mg of GAC, and a regeneration cost of $1.50/lb of GAC.
3. Based on $0.1/kwhr.
4. Based on 1 additional operator per shift and $35/hr.
5. Based on 2% of total WTP cost.
6. Assumes adequate space is available on-site for new equipment.
7. Does not include the costs for additional lime treatment, which was summarized in a separate table.

Savannah Harbor Expansion Project
Chloride Impact Assessment
Savannah WTP Mitigation Alternative
Ozone Feed System
Conceptual Opinion of Probable Cost

CAPITAL COSTS

Description		**30 MGD**	**60 MGD**
Ozone System		$9,600,000	$18,900,000
Electrical and Instrumentation (12% of Subtotal)		$1,150,000	$2,270,000
Paving, Grading, Drainage, & Site work (10% of Subtotal)		$960,000	$1,890,000
Yard Piping (10% of Subtotal)		$960,000	$1,890,000
Capital Cost Subtotal		*$12,670,000*	*$24,950,000*
Mob/Gen Req:	7%	$890,000	$1,750,000
Engineering:	15%	$1,900,000	$3,740,000
Contingency:	20%	$2,530,000	$4,990,000
Total Capital Cost		**$17,990,000**	**$35,430,000**
Total Amortized Capital Cost ($/year)[1]		**$1,568,000**	**$3,089,000**

OPERATION AND MAINTENANCE COSTS

Description	**30 MGD**	**60 MGD**
Liquid Oxygen Usage[2]	$288,000	$575,000
Power[3]	$235,000	$464,000
Labor[4]	$307,000	$307,000
Maintenance[5]	$253,000	$499,000
Total Operation and Maintenance Cost	**$1,083,000**	**$1,845,000**

Notes and Assumptions:

1. Based on 20 years @ 6%.
2. Based on assumed ozone dose of 5 mg/L, a 10% ozone feed, liquid oxygen supply for ozone generation, and LOX cost of $140/ton.
3. Based on $0.1/kwhr.
4. Based on 1 additional operator per shift and $35/hr.
5. Based on 2% of total WTP cost.
6. Assumes adequate space is available on-site for new equipment.
7. Does not include the costs for additional lime treatment, which was summarized in a separate table.

Savannah Harbor Expansion Project
Chloride Impact Assessment
Weyerhaeuser Mitigation Alternative
Reverse Osmosis Pretreatment
Conceptual Opinion of Probable Cost

CAPITAL COSTS

Description		DI Feed Only 1 MGD[1]	Existing Flow 8 MGD[2]
RO System		$2,199,000	$7,352,000
Electrical and Instrumentation (20% of Subtotal)		$440,000	$1,470,000
Paving, Grading, Drainage & Site Work (10% of Subtotal)		$220,000	$735,000
Yard Piping (10% of Subtotal)		$220,000	$735,000
Capital Cost Subtotal		*$3,079,000*	*$10,292,000*
Mob/Gen Req:	7%	$216,000	$720,000
Engineering:	15%	$462,000	$1,544,000
Contingency:	20%	$616,000	$2,058,000
Total Capital Cost		**$4,373,000**	**$14,614,000**
Total Amortized Capital Cost ($/year)[3]		**$381,000**	**$1,274,000**

OPERATION AND MAINTENANCE COSTS

Description	1 MGD	8 MGD
Chemical Usage[4]	$15,000	$91,000
Cartridge Filter Replacement[5]	$3,000	$30,000
Membrane Replacement[6]	$23,000	$135,000
Power[7]	$151,000	$582,000
Additional Water Purchase[8]	$68,000	$411,000
Labor[9]	$307,000	$613,000
Maintenance[10]	$62,000	$206,000
Total Operation and Maintenance Cost	**$629,000**	**$2,068,000**

Notes and Assumptions:

1. Flow rate based on pretreating 1 MGD of flow to the demineralizer with RO.
2. Flow rates based on conversations with Industrial users including flow to demineralizers and to pulp and fiber lines. The amount of flow treated by RO (6 MGD) assumes that 25% of the flow can be bypassed and blended with the RO permeate to meet pre-dredging chloride levels.
3. Based on 20 years @ 6%.
4. Based on 5 mg/L of Caustic at $1.00 per gallon, and 3 mg/L of Antiscalant at $8.00 per gallon, and 1 mg/L of Sodium Bisulfite at $2.00 gallon.
5. Based on assumed change out every 4 months at $20 per cartridge
6. Based on assumed change out every 7 years for all elements in the RO system
7. Based on $0.1/kwhr.
8. Based on water rate of $750/million gallons for purchasing City water and concentrate flow from RO process
9. Based on 2 additional operators per shift and $35/hr.
10. Based on 2% of total WTP cost.
11. Assumes adequate space is available on-site for new equipment.
12. Assumes concentrate disposal by pumping into the wastewater collection system.

Savannah Harbor Expansion Project
Chloride Impact Assessment
International Paper Mitigation Alternative
Reverse Osmosis Pretreatment
Conceptual Opinion of Probable Cost

CAPITAL COSTS

Description	DI Feed Only 4 MGD[1]	Existing Flow 10 MGD[2]	Future Flow 25 MGD[2]
RO System	$5,194,000	$8,072,000	$15,221,000
Electrical and Instrumentation (20% of Subtotal)	$1,039,000	$1,614,000	$3,044,000
Paving, Grading, Drainage & Site Work (10% of Subtotal)	$519,000	$807,000	$2,009,000
Yard Piping (10% of Subtotal)	$519,000	$807,000	$1,522,000
Capital Cost Subtotal	*$7,271,000*	*$11,300,000*	*$21,796,000*
Mob/Gen Req: 7%	$509,000	$791,000	$1,526,000
Engineering: 15%	$1,091,000	$1,695,000	$3,269,000
Contingency: 20%	$1,454,000	$2,260,000	$4,359,000
Total Capital Cost	**$10,325,000**	**$16,046,000**	**$30,950,000**
Total Amortized Capital Cost ($/year)[2]	**$900,000**	**$1,399,000**	**$2,698,000**

OPERATION AND MAINTENANCE COSTS

Description	4 MGD	10 MGD	25 MGD
Chemical Usage[4]	$58,000	$114,000	$285,000
Cartridge Filter Replacement[5]	$14,000	$42,000	$104,000
Membrane Replacement[6]	$90,000	$165,000	$441,000
Power[7]	$151,000	$680,000	$1,791,000
Additional Water Purchase[8]	$274,000	$513,000	$1,300,000
Labor[9]	$613,000	$613,000	$613,000
Maintenance[10]	$145,000	$226,000	$436,000
Total Operation and Maintenance Cost	**$1,345,000**	**$2,353,000**	**$4,970,000**

Notes and Assumptions:

1. Flow rate based on pretreating 4 MGD of flow to the demineralizer with RO.
2. Flow rates based on conversations with Industrial users including water use. The amount of flow treated by RO (7.5 MGD for existing flows and 18.75 MGD for future flows) assumes that 25% of the flow can be bypassed and blended with the RO permeate to meet pre-dredging chloride levels.
3. Based on 20 years @ 6%.
4. Based on 5 mg/L of Caustic at $1.00 per gallon, and 3 mg/L of Antiscalant at $8.00 per gallon, and 1 mg/L of Sodium Bisulfite at $2.00 gallon.
5. Based on assumed change out every 4 months at $20 per cartridge
6. Based on assumed change out every 7 years for all elements in the RO system
7. Based on $0.1/kwhr.
8. Based on water rate of $750/million gallons for purchasing City water and concentrate flow from RO process
9. Based on 2 additional operators per shift and $35/hr.
10. Based on 2% of total WTP cost.
11. Assumes adequate space is available on-site for new equipment.
12. Assumes concentrate disposal by pumping into the wastewater collection system.

Savannah Harbor Expansion Project
Chloride Impact Assessment
International Paper and Weyerhaeuser Mitigation Alternative
Demineralization Alternative
Conceptual Opinion of Probable Cost

CAPITAL COSTS

Description		**Weyerhaeuser 1 MGD**	**International Paper 4 MGD**
Demineralization System		$2,750,000	$11,000,000
Electrical and Instrumentation (12% of Subtotal)		$330,000	$1,320,000
Paving, Grading, Drainage, & Site work (10% of Subtotal)		$275,000	$1,100,000
Yard Piping (10% of Subtotal)		$275,000	$1,100,000
Capital Cost Subtotal		*$3,630,000*	*$14,520,000*
Mob/Gen Req:	7%	$254,000	$1,016,000
Engineering:	15%	$545,000	$2,178,000
Contingency:	20%	$726,000	$2,904,000
Total Capital Cost		**$5,155,000**	**$20,618,000**
Total Amortized Capital Cost ($/year)[1]		**$449,000**	**$1,798,000**

OPERATION AND MAINTENANCE COSTS

Description	**1 MGD**	**4 MGD**
Chemical Usage[2]	$592,000	$2,368,000
Resin Replacement [3]	$125,000	$500,000
Power[4]	$8,000	$32,000
Labor[5]	$0	$0
Maintenance[6]	$73,000	$290,000
Total Operation and Maintenance Cost	**$798,000**	**$3,190,000**

Notes and Assumptions:

1. Based on 20 years @ 6%.
2. Based on usage estimates for Caustic (NaOH) and Hydrochloric Acid (HCl).
3. Based on estimated resin replacement of 5-10% a year.
4. Based on $0.1/kwhr.
5. Assumes no additional operators are required.
6. Based on 2% of total treatment cost.
7. Assumes adequate space is available on-site for new equipment.