A Case Study for Industrial Wastewater Desalination and Concentrate Disposal Barriers in Florida

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EDITOR'S NOTE: The following article received a Top Paper Honorable Mention Award at the Florida Section AWWA Fall Conference in November.

URS Corporation (URS) conducted a treatability study coupled with a desk top analysis involving the use of chemical softening and membranes to manage an existing industrial wastewater discharge from an industrial manufacturing facility in order to meet pretreatment requirements of the local publicly owned treatment works (POTW). The POTW is regulated by the Florida Department of Environmental Protection (FDEP) and the U.S. Environmental Protection Agency (EPA).

The raw water source is a unique industrial source wastewater containing high levels of organic matter, total dissolved solids (specific conductance), and oversaturated gypsum at a high pH level exceeding 10.0. Several innovative water treatment technologies, including a pressurized CO_2 injection system for better chemical softening and pH control and weak acid cation exchange followed by high recovery (90 percent ~ 95 percent) reverse osmosis (RO), were evaluated to address current POTW compliance issues; however, decisive barriers for concentrate disposal were found and the ability to apply a membrane treatment solution to address future wastewater compliance was substantially reduced.

This paper presents the results from a desktop analysis, a set of laboratory jar tests, and a full-scale pilot study associated with a proposed strategy to optimize the facility's existing chemical softening process.

POTW Standards & Wastewater Characteristics

Prohibited Discharge Standards and Categorical Standards are found in Chapter 40 CFR, which calls for the protection of POTWs, prevention of pollutant "pass through" into receiving waters, and reclamation of sludge. More stringent local limits have been proposed by the local POTW in accordance with 40 CFR 403.5, which allows individual POTWs to develop local limits in order to protect them from upsets that would lead to noncompliance with their discharge permit.

In this case, the POTW discharge is via surface water and is regulated through a National Pollutant Discharge Elimination System (NPDES) permit. In 2003 the POTW entered into a consent order with the FDEP concerning effluent specific conductance. In the agreement, the POTW can discharge effluent containing no more than 1,900 µmhos/cm until March 31, 2007, after which the conductance must be reduced and remain below 1,275 µmhos/cm.

Table 1 lists the historical finished water quality data of the facility. The existing facility failed to comply with the current POTW conductivity limit. Also, current sodium levels in the effluent of the facility exceed the future limit.

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Configuration & Operation of Existing System

The manufacturing facility has three plants that run in a parallel configuration, which produces their products. Each plant has its own dedicated wastewater treatment system. Each system contains the same unit treatment processes: a batch process consisting of an excess tank where wastewater is stored prior to treatment, a CO_2 contact chamber, followed by a clarifier and bag filters.

The existing wastewater treatment system is a one-stage, CO_2 injection system. The CO_2 injection system consists of a recycle stream; part of the clarified water is recycled from the clarifier back to the CO_2 contact chamber to meet the target pH level prior to

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Values	Chloride	Conductivity	Sulfate	TDS	Sodium
POTW Current Standard	NA	3,700	NA	NA	NA
POTW Proposed Standard	NA	1,275	NA	NA	265
Average	444	3,555	814	2,720	363
Max	620	4,450	1,100	3,104	524
Min	238	3,020	528	2,218	238

Note: All values expressed in milligrams per liter (mg/L) except for the conductivity values, which are expressed in µmhos/cm.

Figure 1 – Existing Chemical Softening System at Industrial Facility

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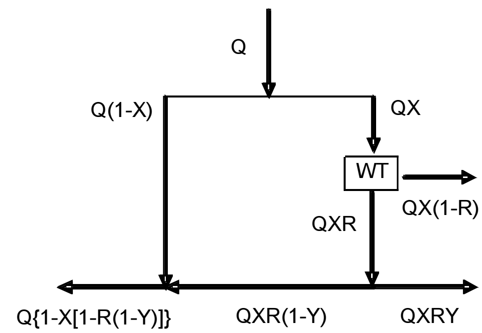
discharge to the POTW (i.e., pH = 6~8.5).

Figure 1 depicts the equipment associated with the existing chemical softening system. Approximately 250,000 to 350,000 gallons per day of effluent wastewater are discharged to the POTW.



Where:
Q = Full effluent flow (kgallon/day)
X = Rate of partially treated water (%)
R = System recovery rate (%)
Y = Water reuse rate (%)
WT = Water treatment plant
QX = Feed flow to water treatment plant (kgallon/day)
QXR = Treated water to blend/reusing (kgallon/day)
QXRY = Treated water to reuse (kgallon/day)
QXR(1-Y) = Treated water to blending with untreated water (kgallon/day)
Q{1-X[1-R(1-Y)]} = Blended water discharge to POWT (kgallon/day)

Figure 2 – Flow Diagram for Chemical Softening Process

Wastewater Characterization

Prior to testing, URS conducted a comprehensive sampling event. Findings from the results of multiple sample events, along with initial observations on the existing treatment system, are summarized as follows:

- The water is supersaturated with $CaCO_3$, $BaSO_4$ and $SrCO_3$.
- The water contains a high organic content (NPDOC > 50mg/L).
- Effluent conductivity levels in the treated effluent often times are close to or exceed the city's current discharge limit.
- Sodium levels are higher than the future POTW limit.
- The existing one-stage CO_2 injection system has marginal organic removal capability and no sodium reduction.
- The existing system is inefficient for calcium removal with the one-stage CO_2 injection system over a pH range 6 to 8.5. Over this pH range, a portion of the calcium carbonate was stabilized to calcium bicarbonate.

Desktop Alternative Analysis & Optimization

In order to reduce the specific conductance (as well as sodium levels) of the industrial wastewater stream before discharge to the POTW, various treatment technologies were considered. A screening was performed initially to retain viable options for a more detailed analysis. Table 2 summarizes the alternatives that were evaluated through an initial desktop analysis.

From the initial screening, two conceptual treatment strategies (Strategies A and B) were developed which could be applied to the subject facility to address the stated wastewater compliance objectives. Here is a summary of each strategy:

- *Strategy A* includes modifications to the facility's existing chemical softening process coupled with segregation of some internal waste streams, followed by a direct discharge to the sanitary sewer system. This strategy would be explored first as a means to optimize the existing treatment system, which could potentially yield a reduction in specific conductance levels. The strategy would also minimize the overall capital cost associated with treating effluent produced by the facility.
- *Strategy B* includes (1) Chemical Softening, (2) Chemical Coagulation, (3) Acidification, (4) Chloramination, (5) Filtration, (6) Weak Acid Cation exchange (WAC), (7) RO, and (8) Reuse/Blending/Discharge. Alternative B was developed based on a review of viable treatment technologies that could be coupled together to properly address wastewater compliance. This strategy would require a substantial capital investment and could be applied only if a suitable and cost-effective disposal route could be identified for brine generated by the membrane system.

Since Strategy A would be utilized as part of the pretreatment process associated with Strategy B, it was evaluated initially. A mass balance was constructed for Strategy A, followed by a series of jar tests.

The mass balance was constructed by developing an array of potential operational settings associated with the modified chemical softening process. In the modified process, the existing chemical softening process would be switched from a batch mode to continuous flow mode. In addition, two injection points of CO_2 would be used to optimize the softening process, while ensuring neutral pH conditions prior to discharge to the POTW. The mass balance constructed for the modified system is illustrated in Figure 2, and Table 3 provides a summary of the potential operational settings that could be considered for the system.

Table 2 Prescreened Applicable Technologies for Removal of Dissolved Solids

Number	Processes
1	Management and Segregation of Internal Waste Streams within Facility
2	Chemical Softening
3	Nanofiltration Membrane (Membrane Softening)
4	Reverse Osmosis Membrane
5	Electrodialysis or Electrodialysis Reversal
6	Ion Exchange

Table 2 Prescreened Applicable Technologies for Removal of Dissolved Solids

Table 3 Description and Variable Range for System Optimization

Parameter	Range of Variables Considered in Analysis									
Q	350									
X	60	70	80	90	100					
R	80	90	95							
Y	0	10	20	30	40	50	60	70	80	90	100

Note: *All values are expressed in thousand gallons per day (kgpd).*

Jar Tests & Findings

In order to evaluate the potential reduction in specific conductance levels associated with Strategy A, a series of jar tests were conducted. URS, in conjunction with the environmental engineering department at the University of South Florida (USF), collected a series of raw wastewater samples from the facility and used them to conduct the jar tests.

Figure 3 is a series of photographs show-

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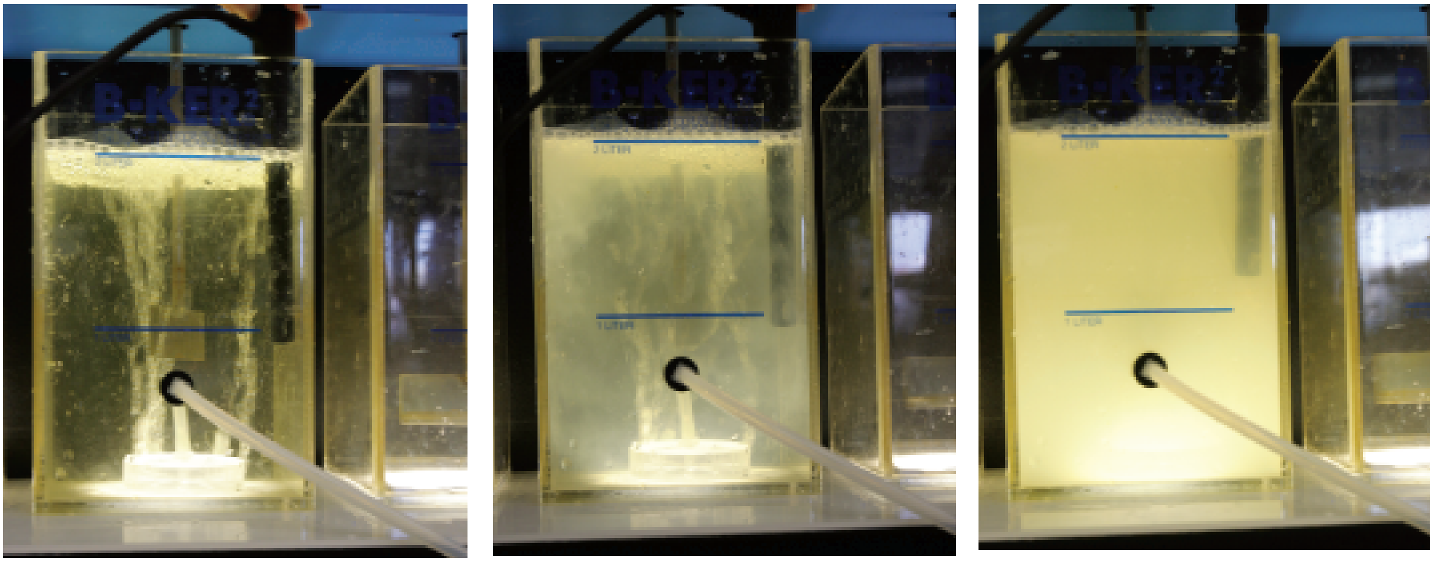

Figure 3 - Jar Test at Optimized pH Level (1st Stage CO2 Injection)

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ing the precipitation of calcium hardness during the first-stage CO_2 injection at a pH level of 10.5.

Bench-Scale Findings

A pH level of 10.5 was established to be the optimized pH level for conductivity reduction. Further reducing pH to lower than 8.5 may cause CaCO3 restablization and consequently may increase conductivity.

The effect of pH reduction on conductivity and dissolved calcium concentrations is shown in Figure 4a through 4d for the November 3, 2004, samples. The figure shows that conductivity and calcium levels decreased, then increased, with further reduction of pH, most likely due to the increasing solubility of calcium carbonate as a function of decreasing pH. Further reduction of pH lower than 8.5 caused $CaCO_3$ restablization and consequently increased conductivity.

Jar-test samples were collected concurrently when field measurements were conducted. The resulting conductivity levels documented during jar testing versus those with-

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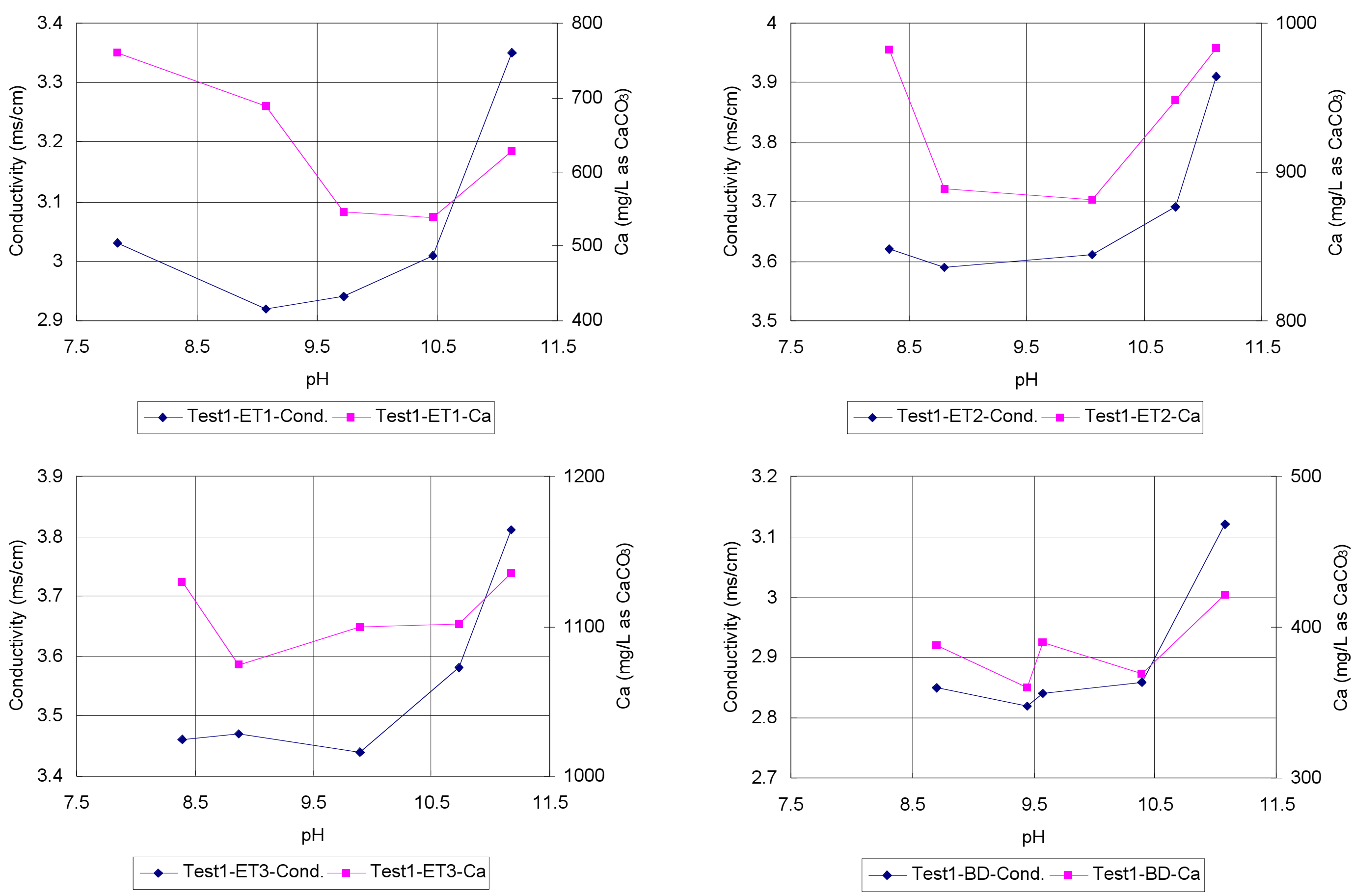

Figure 4 – Jar Test Results

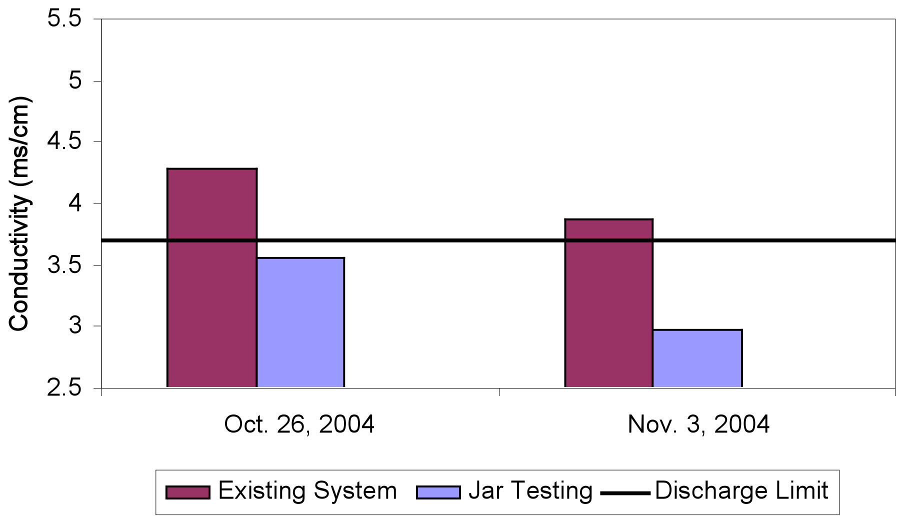

Figure 5 - Conductivity of Treated Water from Existing System and Jar Tests

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in treated effluent produced by the existing facility were compared. The results demonstrated that conductivity can be reduced to meet the current limit.

Figure 5 shows the comparative conductivity values between the existing treatment system and jar testing. For the October 26 sample, Clarifier 1 effluent conductivity from the existing system was reduced from 4.29 ms/cm to 3.56 ms/cm. For the November 3 sample, Strategy A improved conductivity from 3.87 ms/cm to 2.97 ms/cm.

Full-Scale Pilot of Strategy A at Facility

In January and February 2005, the facility leased a two-stage carbon dioxide injection panel from TomCO2 Inc. and installed it at one of their three existing wastewater treatment plants within the facility. Subsequently, various modifications were made to the existing system to allow the system to remain in operation in a continuous flow mode (versus batch operation).

The modified system was initially operated and adjustments were made to the first- and second-stage CO_2 injection assemblies in order to optimize the full-scale system by maintaining an initial pH level of 10.5 within the mixing tank and a neutral pH level after the second-stage injection. In addition, the recycle stream that was previously used was eliminated.

Initial results documented after the modifications were implemented mimicked those observed during the bench-scale testing program. Effluent conductivity levels from the full-scale system were documented below 3,000 µmos/cm.

Based on the successful application of the two-stage carbon dioxide system at the subject facility, the resulting effluent conductivity produced by the facility meets the current POTW standard for this parameter. The facility has proceeded with purchasing permanent units to replace the leased units, as well as purchasing two additional units to modify their other wastewater treatment systems. These additional units were being installed at the time this article was published.

Concentrate Disposal Barrier of Strategy B

By implementing Strategy A, the facility will meet the current conductivity limit; however, to meet future conductivity and sodium limits, Strategy B is technically feasible to produce high-quality water for internal reuse or discharge to the city POTW, assuming sufficient pretreatments are provided.

The disposal of brine becomes decisive for Strategy B. The following concentrate disposal methods were explored:

- Off-Site Hauling to Another POTW—Analysis showed that a practical option is to haul brine off-site for disposal at a POTW that has an ocean discharge. POTWs with an ocean discharge within 50 miles distance to the site were contacted, but based on feedback from plant managers, none can take the water with high total dissolved solids (TDS) because of their reuse programs. Some large facilities, like the Howard Curren Wastewater Treatment Plant in Tampa, could take this wastewater in the past, but they have implemented their reclaimed water service, so industrial wastewater containing relatively high levels of TDS and conductivity are not being accepted in any quantities. No other treatment plants are within an acceptable range to make this option cost effective because of transportation costs. Based on the results from the investigation, this option does not appear to be viable.
- Off-Site Hauling to a Series Of Evaporation Ponds—No on-site land is available for an evaporation pond. Generally, evaporation ponds are not an attractive option in Florida due to prolonged periods of heavy rainfall in the region. A quick estimate of land requirement was done using LandApp98 software developed by the FDEP. By assuming site hydraulic capacity (permeability) equal solely to evaporation rate and utilizing the closest weather station's monthly precipitation data, an uncovered storage volume was calculated that would be required to manage the daily quantity of brine generated by the membrane treatment system. Results showed that an evaporation pond with 20 surface acres would be required; hence, this option was not recommended for further evaluation.
- Off-Site Hauling to a Permitted Industrial Injection Well—URS met with representatives of the FDEP to investigate sites that may already have existing permitted industrial wastewater injection wells. Feedback from the local UIC program indicated very few Class I industrial injection wells located near the facility. The closest known industrial injection wells are located in Mulberry and Sarasota County. The well at the Mulberry facility did not have sufficient capacity and the hauling costs to Sarasota would be excessive, so this alternative was not considered viable for these reasons.
- On-Site Brine Disposal via Injection Well—Per a meeting with the FDEP's UIC division, a Class I injection well would be required to route the brine waste into a deep underground formation that is not now nor expected to be used as a source for drinking water. An extensive literature review on the local geology indicated the uncertainty of a viable injection zone in the area. Moreover, the brine is expected to contain high organic content as well as supersaturated salts, which may plug the well and have a negative impact on injectivity. Deep-well injection can only be a reasonable method provided that long-term operation can be maintained. Initial cost estimates to permit, construct, and test a new injection well on site was considerable, running into millions of dollars. In addition, the time frame that would be necessary to set up an injection well could take years to five years, which would exceed the amount of time that the facility has to meet the proposed discharge limits of the POTW. Due to the time frame associated with the proposed POTW discharge standards, on-site brine disposal via a new on-site injection well is not likely and was eliminated as a feasible option.
- On-Site Brine Evaporation Using a

Crystallizer—This appears to be the only viable solution, although the capital and O&M costs associated with the zero discharge equipment may be excessive. For a 0.3-mgd scale plant, even at a 90 percent~95 percent high recovery rate, the conceptual evaluation showed the capital and O&M costs of a crystallizer will be equal to or even exceed the cost of the entire wastewater pretreatment system; consequently, the facility has decided that this option is not feasible, at least at this time.

At the time this article was written, the facility was re-evaluating its internal operations and the various products that contribute to TDS, conductance, and sodium in its manufacturing process. It may be possible to reduce the amount of solids that are dissolved into water within the facility to a point at which the resulting wastewater stream (with the use of Strategy A) will meet the POTW's proposed discharge limit. If it does not, some form of membrane treatment with additional pretreatments will likely have to be explored and implemented; however, by better managing the internal materials used in the manufacturing process to limit the amount of solids entrained in water (leading to high conductivity and sodium levels), a smaller pretreatment and brine disposal system would be required, minimizing cost impacts to the facility.

Conclusions

The modified chemical softening system at this industrial facility proved effective in reducing effluent conductivity levels below current POTW standards by optimizing the chemical softening process. This modification required minimum equipment and effort, minimizing the amount of capital and labor required to reach the compliance requirements associated with the discharge to the POTW; therefore, the implementation of Strategy A proved to be successful and is being considered for use at company's sister facilities.

With that being said, future industrial wastewater compliance to meet both the lower conductivity level and sodium levels remain problematic. The mixture of high organic content, coupled with tight pH control associated with the chemical softening process, will substantially limit the number of viable technologies that can be explored to further reduce dissolved solids and conductivity.

Membrane treatment or forced mechanical evaporation may be required to address future compliance requirements associated with the discharge from this facility. Neither of these options are inexpensive, and substantial logistical issues are associated with the membrane solution—specifically, the issue of brine management and disposal. In-house modifications to reduce those factors leading to high conductivity in the wastewater generated by the facility—including source reduction, alternative manufacturing processes or techniques, or other internal changes—may be required.

While the local POTW industrial pretreatment program that serves this particular facility proposes more stringent local limits, it will impact all industrial clients that have historically relied on the POTW to manage wastewater containing relatively high levels of conductivity (salinity) and sodium.

The promulgation of tighter discharge standards is a direct consequence of the POTW's continued reliance on a fresh surface-water discharge to dispose of effluent in an effort to comply with FDEP and EPA regulations. The implications associated with conductivity regulation by other POTWs, whether due to fresh surface waters or standards associated with production of reclaimed water for irrigation purposes, can potentially result in significant impacts to any industry whose wastewater contains high levels of dissolved solids/specific conductivity; therefore, the authors firmly believe that similar industrial facilities should carefully investigate the ultimate route of treated effluent from POTWs, since substantial cost savings could result from better management of effluent containing high conductivity levels.