Integration Of Flood Control, Wetland Habitat, Reuse, Recreational Features and Stormwater Treatment

Mitchell D. McKnight, Daniel J. Homblette, and Terry W. Liby

arasota County has begun the development of the first of several large regional multi-use stormwater facilities based on watershed scale planning and modeling studies. The concept evolved from modeling the Phillippi Creek watershed after a 1992 storm caused widespread flooding. Planning and preliminary design have been completed for a 300-acre facility storing up to 1,000 acre-feet of stormwater during infrequent storm events. The site is also being designed to provide water quality treatment of base condition flows, storage for possible reuse of stormwater, wetland community habitat throughout the system, a dedicated mitigation bank, and recreational facilities for the citizens of Sarasota County.

The Main "C" Regional Stormwater Facility (known as the Celery Fields Project) is a 300-acre agricultural area acquired by Sarasota County for conversion to a multi-purpose regional stormwater facility. The project is being administered by the Sarasota County Stormwater Environmental Utility (SEU). Boyle Engineering Corporation was selected by Sarasota County to provide planning, design, permitting, construction phase, and monitoring services for the project.

Historically, the site was an agricultural area within the Phillippi Creek drainage basin and adjacent to the Main "C" Canal, a tributary to Phillippi Creek. The fields were subject to regular, periodic inundation by the adjacent drainage canal. The floodplain was extensively cleared, ditched and diked in the 1940's to allow agricultural use.

Sarasota County SEU began development of the Phillippi Creek Basin Master Plan in 1991 in response to severe flooding conditions within the basin. The basin study identified the potential for a regional flood control facility at the Celery Fields site. Severe flooding in June, 1992 prompted Sarasota County to purchase property at the site and begin detailed planning for the facility.

Sarasota County SEU realized the potential for creating a multi-purpose facility. The primary goal of the project remains flood control. Additional goals of the project include water quality enhancement through sedimentation aeration and filtration, restoration of wetlands and creation of a wetland mitigation bank, augmentation of the County's wastewater reuse system and creation of a passive recreational and educational facility.

Boyle Engineering Corporation began Phase I (preliminary design) for the project in July, 1994. It included field surveying, hydrologic and hydraulic design for stormwater storage for flood attenuation, treatment for water quality and potential alternate reuse water supply source, evaluation of a potential wetland/wildlife habitat area, assessment of environmental permitting requirements, soil exploration, preliminary cost analyses, and preliminary right-of-way plans. Phase I was completed in May 1995.

Phase 2 services consist of preparation of construction plans and specifications, permitting, development of operation and maintenance manuals and funding assistance. Anticipated completion for Phase 2 is fall 1996. Construction, anticipated to take two years, will be followed by extensive water quality and quality monitoring, which will include recommended adjustments to the operation and maintenance of the facility.

Interagency Coordination

A project of this size and complexity requires close coordination and communication with all levels of the regulatory community. From the very beginning there were communications with agency and department representatives regarding permitting, wetland jurisdiction, technical assistance, participation in and use of the project, and financial assistance. The primary permitting agencies included SWFWMD, DEP, the Corps of Engineers, and the Sarasota County Natural Sciences Division. In addition, wildlife review agencies, including the Florida Game and Fresh Water Fish Commission and the US Fish and Wildlife Service, were consulted regarding endangered and threatened species documentation, permitting, and design features that should be considered to enhance wildlife habitat and fisheries. Furthermore, the following agencies were also consulted: Soil Conservation Service (soils and agricultural management practices utilized in the existing muck farms), Sarasota County Mosquito Control District (existing mosquito control practices and potential practices to be implemented for the project), Sarasota Bay National Estuary Program (general information regarding Phillippi Creek and downstream water quality), and the Sarasota Parks and Recreation Department (soccer fields). Meetings were also held with representatives of Fancee Farms, the current owner of the property and farming operation.

The two key agencies for wetland jurisdiction were the Corps of Engineers and SWFWMD, with representatives from both agencies visiting the site to establish the respective jurisdictions. Basically the COE claimed most of the site based on the strong presence of hydric soils (Floridana mucky fine sand), and SWFWMD exerted its jurisdiction only within the swales, ditches, and canals that had sufficient hydrology to maintain wetland vegetation. One of the key issues regarding wetland jurisdiction and potential impacts was the recognition by the agencies of the ultimate benefit of the project in converting agricultural fields to a more natural system.

Flood Control/Water Quality

Design of the facility is based on results from the Phillippi Creek Basin Master Plan completed in December 1994. The total basin contains 57 square miles, with 6 square miles upstream of the site. It was estimated that 1000 acre-feet of stormwater storage at the Celery Fields site, achieved by gravity flow or pumping, would provide a 100 year flood stage reduction of 1.6 feet in a densely populated area downstream, resulting in the removal of 168 homes from the flood plain.

Facility design is based on hydrologic and hydraulic modeling using the EPA's modified Stormwater Management Model (SWMM 4.05) and the COE HEC-2 computer model. Prelimi-

nary results indicate slightly greater than 1000 acre-feet can be stored without requiring pumping. Sarasota County will be able to take advantage of a weir upstream on the Main "C" at the site and reroute the flow into the facility. The model is based on storing flood waters above the seasonal high water elevation. Greater storage will be available during dry periods and, by not lowering groundwater elevations, the impacts to adjacent properties will be reduced.

Tributaries to Main "C" enter the canal at a lower elevation than will be realized during storm events. A perimeter canal will be constructed around the eastern boundary of the site to intercept flow that normally traveled west through the Celery Fields. The canal will redirect the flow into Main "C" downstream of the Celery Fields outfall to prevent backwater from affecting adjacent properties.

A series of cells will be designed to create the treatment train process. The first cell will be a 58-acre sedimentation basin. Trash racks will assist in debris removal. Cell 2 consists of a 30-acre lake surrounded by 70 acres of open park space and four soccer fields. Elevations are established such that the park space will be inundated during the 5-year storm event and soccer fields inundated during the 25-year storm event. Cell 3 consists of a 105-acre wetland/wildlife habitat area. All three cells will have adjustable outfall structures to allow flexibility in controlling frequency and depth of inundation. The structures will also be used during the phasing of construction to allow total or partial isolation of each cell. The flexibility of these structures will prove important as Sarasota County seeks to balance the effects of highly variable storm events. Very little background water quality data is available for the Main C system. Sampling is currently underway and predicted annual load reductions will be calculated. A water quality monitoring program will be established for the project site, and the actual reduction in nutrients, metals, and sediment will be documented. Flexibility in the control structures will allow for adjustments to enhance treatment.

Wetland Creation/Restoration - Mitigation Bank

There are no remnants of the original sawgrass wetland remaining in the immediate vicinity of the project. A portion of the value that wetlands provided to the basin will be realized again by the project. While much of the water quality treatment provided by the project will come from the sedimentation and aeration/lake systems, wetlands will also provide filtration and nutrient removal. In addition, integrating them into the shoreline will provide habitat and protection of the shoreline from an erosion caused by wave action and fluctuating water levels. The diverse wetland system created as a mitigation bank will provide the most valuable habitat within the project. This area will include open water, shallow marsh, forested wetland, and wet meadow. The final design will be based on habitat created to mitigate potential impacts to species currently utilizing the site and the elevations/ storage required to fulfill the flood storage requirements.

Reuse

The Sarasota County Utilities Department's Regional Wastewater Reuse Master Plan, completed in November, 1994, identified the Celery Fields project as a potential source for supplementing the reuse system with stormwater as a means to smooth out the peaks and valleys of supply and demand.

Stormwater flows into the site contain many transportation related and agricultural types of pollutants. The three-cell design of the facility will greatly reduce the amount of pollutants flowing into Main "C" canal and eventually into Sarasota Bay. Cells 1 and 2 (sedimentation and aeration) will remove organic materials, suspended solids nutrients and heavy metals. Cell 3 (filtration via wetlands) will further "polish" the stormwater from Cells 1 and 2. It is expected the treated stormwater will meet DEP rules for reuse water.

Ninety percent of the annual rainfall of 61 inches occurs in a four-month period and produces approximately 5,400 acre-feet of runoff in Main "C" Canal at the Celery Fields site. A base flow of approximately 3,300 acre-feet per year must be allowed to discharge into Main "C" canal to address environmental concerns. This makes approximately 2,100 acre-feet available to "capture," store, and introduce into the reuse system.

Storing the excess stormwater is a complicated issue. Storage on site at the Celery Fields is not feasible because flood control must be available during the wet season. The treated stormwater cannot be introduced directly into the reuse system because demand is low during the wet season. Alternatives to storage include on-site storage, expansion of the Celery Fields project to include storage adjacent to the project, and off-site storage. A 150-acre lake formerly used as a borrow and located two miles north of the project can accommodate a rise in normal pool elevation of two feet, creating a storage volume of 300 acre-feet. Sarasota County will pursue acquiring rights for storage of the treated stormwater at this site.

Recreation/Education

From the beginning it was critical to incorporate the human element from a recreational and educational standpoint. The basic recreational opportunities include walking, jogging, and bicycling around the 1.8 mile path surrounding the lake, fishing, and picnicking at the shelters. In addition, the County is developing a soccer complex with four fields and plans to add four more. The educational opportunities include information on the history of the site (sawgrass wetlands, agricultural operations, and a multi-use facility), and the present day flood control, stormwater treatment, wetlands, wildlife habitat and reuse functions. The information will be presented in wide variety of ways through on-site kiosks and displays, brochures, programs presented to individuals and interest groups and close coordination with the school system.

Conclusion

The development of this multi-purpose flood control, stormwater, wetlands, recreation, and reuse facility has required progressive thinking and close coordination of many disciplines and numerous governmental agencies. The result is a one-of a-kind facility that has great potential for many communities and, in fact, is the first of several within Sarasota County. This approach to environmental management results in a beneficial use of the taxpayers money to solve a significant environmental problem.

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Soil Adsorption of Zinc According to the Freundlich Isotherm

James M. Chansler, William G. Lloyd, and Donald R. Rowe

PA's 40 CFR Part 503 standards for sewage sludge use and disposal will have significant impacts on the management of wastewater sludges in the United States. The rule addresses three different ways of handling biosolids disposal: disposal at dedicated sites or sludge-only landfills (monofills), incineration at sludge-only incinerators, and the application of biosolids to land (Sieger and Hermann, 1993). EPA encourages the latter alternative, which has become the method practiced by 17 percent of producers in the U.S. (Aitken and Mullennix, 1993).

Subpart B of 40 CFR Part 503 lists numerical standards, operational standards, management practices, monitoring and reporting requirements, and record-keeping requirements for the land application of biosolids. The three classes of pollutants governed by the rule are metals, organics, and pathogens. While all three classes are important, metals are of particular importance due to their impact on limiting disposal site life.

One way for regulatory agencies or municipalities to analyze the impact of trace metals on the environment is to look at adsorption rates. Adsorption is a surface phenomenon often used to remove trace levels of contaminants from either a liquid or a gas stream by contact with a solid surface referred to as the adsorbent (e.g., activated carbon, molecular sieves, silica gel, natural soils, etc.). The adsorption phenomenon is influenced not only by the type of adsorbent used, but also by the molecular size and polarity of the contaminant, the nature of the solution or gas stream in which the contaminant is dispersed, and the contacting system employed. It is important to be able to relate the amount of contaminant adsorbed from the gas or water stream to the amount of adsorbent needed to reduce the contaminant to an acceptable level.

A purely empirical equation often used to describe this adsorption or sorption phenomena is the Freundlich isotherm.

$$X/M = KC^{1/n}$$

Where X/M = the mass (X) of the element or contaminant adsorbed from solution per unit mass of adsorbent (M).

K, n = Constants fitted from the experimental data.

C = The concentration of the metal ion or contaminant in the solution phase at equilibrium.

By taking the logarithm of both sides, this equation is converted to a linear form.

$$\log X/M = \log K + 1/n \log C$$

If the experimental data fit the Freundlich Adsorption Isotherm, a plot of $\log X/M$ versus $\log C$ (or X/M versus C on log-log axes) gives a straight line as shown in Figure 1.

From Figure 2, the constants K and n were graphically found to be 0.0034 for K at a zinc concentration of 1 mg/L, and 1.2 for n. For the computer program (BASIC) presented in Figure 3 which includes a least square regression analysis, the K value was found to be 0.0040 and an n value of 1.02. The graphical $(X/M) C_o$ value was found to be 0.0052 while the computer program gave a value of 0.0066. The $(X/M)C_o$ value gives the ultimate capacity of a soil sample for sorption of zinc at the initial zinc concentration, which in this case was 1.65 mg/L. Using the BASIC program value, the ultimate capacity of the soil for the sorption of zinc at an initial concentration of 1.65 mg/L would be 6.6 mg of zinc per gram of soil (0.0066 X 1000 mg/g).

Figure 4 shows a printout of the computer results for the sorption data presented in Table 1 (Lloyd, 1992).

Figure 1. Determination of constants (on non-log axes) for the Freundlich adsorption isotherm (Sundstrom and Klei, 1979).

The average Zn concentration in the area's treated wastewater used for spray irrigation was determined to be 0.23 mg/L. Based on this Zn concentration and the computer calculated constants, the soil would have a sorption capacity of:

$$X/M = K \, C^{1/n}$$
$$= 0.0040 \, (0.23)^{1/1.02}$$
$$= 0.00095$$

The soil sorption capacity at this zinc concentration is then 0.95 mg:gram of soil.

If a vertical line is erected from a point on the horizontal scale corresponding to the initial contaminant concentration (Co) and the isotherm extrapolated to intersect that line, the X/M value at this point of intersection can then be read from the vertical scale. The value of $(X/M)C_o$ represents the amount of contaminant adsorbed per unit weight of adsorbent when that absorbent is in equilibrium with the initial contaminant con-
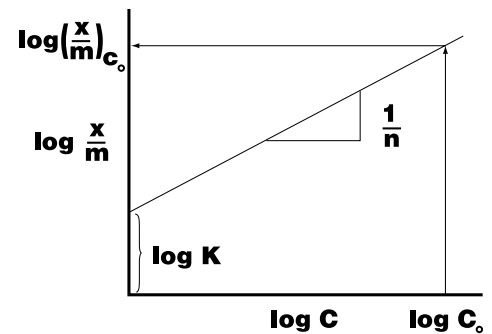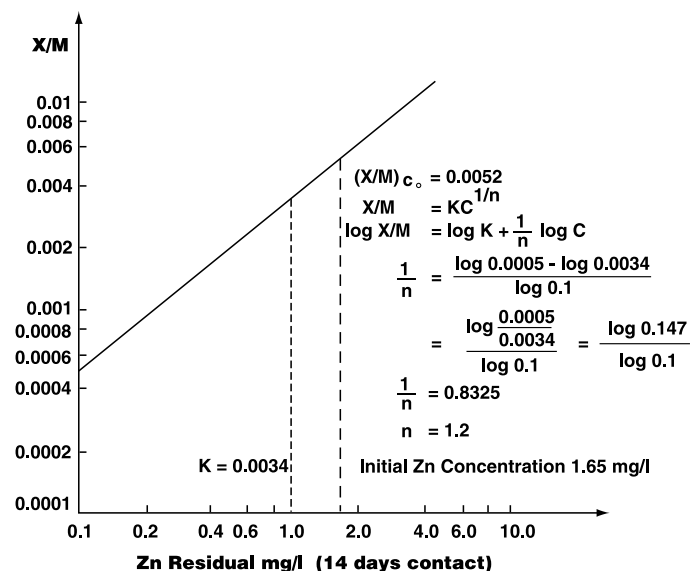

Figure 2. Zn sorption by Dirab Soil according to Freudlich isotherm (Rowe, et. al., 1987). Log-log axes are used so that values for X/M and C can be read directly from the graph.

Figure 3. Program FREUNDHC: Freundlich Isotherm Calculations (BASIC).

```
100  CLS
110  ************Freundlich Adsorption
     Isotherm************ :LPRINT
120  DIM C(50),L(50),M(50),P(50),Q(50),X(50),Y(50):
     Z=2.302585093#
130  INPUT"Name of Adsorption material: ";N$
140  INPUT"Name of Contaminant material: ";C$
150  INPUT"Number of measurements: ";T
160  INPUT"Control value (mg / L): '';CO
170  FOR I=1 TO T:PRINT
180  PRINT''Measurement #";I;" mg/L of ";N$;"
     ";:INPUT M(I)
190  INPUT"mg/L of Contaminant remaining in
     solution: "; C(I)
200  X(I) = CO - C(I) :REM amount of adsorbed
     contaminant
210  Q(I) = X(I)/M(I)
220  NEXT I:LPRINT
230  REM Q(I) is g. of adsorbed contaminant per g.
     of adsorption material
240  CLS:LPRINT".....................Input
     Data....................LPRINT
250  LPRINT TAB(I)"Concn.
     of";TAB(12)"Contaminant";TAB(27)"Contaminant''
260  LPRINT"Adsorbent";TAB(13)''Still
     in";TAB(Z8)"Adsorbed";TAB(45)"X/M"
270  LPRINT" mg/L'';TAB(13)''601n, mg/
     L";TAB(29)"mg/L";TAB(45)"mg/g"
280  LPRINT''———";TAB(11)"————————
     ";TAB(27)"—————";TAB(43)"—
290  FOR I=1 TO T
300  LPRINT M(I),C(I),X(I),Q(I)*1000!
310  NEXT I
320  LPRINT: LPRINT"Control value used was ";CO;"
     mg/L"
330  LPRINT:LPRINT
340  LPRINT"....................Calculations
     ....................":LPRINT
350   LPRINT TAB(3)"C";TAB(ll)''log C";TAB(21)"log
     (X/M)";TAB(34)"log(C^2)";TAB(' "logC*(log[X/
     M])"
360   LPRINT"—— ——— —————— —————— ————
     —"
370  FOR I=1 TO T
380  L(I)=LOG(C(I))/Z
390  REM L(I) is log of contaminant still in soln (mg/L)
400  C2=L(I)^2
410  IF X(I)=O THEN C3=0: GOTO 440
420  C3=LOG(X(I))/Z
430  REM C3 is log of adsorbed contaminant (in
     mg/L water)
440  C4=LOG(M(I))/Z
450  REM C4 is log of adsorbent concn. (in mg/L
     water)
460  Y(I)= C3-C4
470  REM Y(I) is log(adsorbate grams / adsorbent
     grams)
480  C6=L(I)*Y(I)
490  A1=AI+L(I): A2=A2+Y(I): A3=A3+C2: A4=A4+C6
500  LPRINT USING "# .### ##.###### ##.######
     ##.###### ##.######"; C( I ), (I),Y(I),C2,C6
510  NEXT I
520  LPRINT:LPRINT:LPRINT".......................Results

530  LPRINT:LPRINT"Using ";N$;" to remove '';C$;":":
     LPRINT
540  LPRINT"sum of log(C) 's:  "; :LPRINT
     USING"##.#####";A1
550  LPRINT"sum of log(X/M)'s: '';:LPRINT
     USING"###.#####";A2
560  LPRINT"sum of (log C)^2's: '';:LPRINT
     USING"##.#####";A3
570  LPRINT"sum of (log C * log[X/M]): ";:LPRINT
     USING"##.#####";A4:LPRINT
580  D=T*A3 - A1^2
590  D1=A2*A3 - A4*A1
600  D2=T*A4 - A2*A1
610  S=D2/D: I=D1/D
620  S=ABS(S)
630  LPRINT''SLOPE =            ;:LPRINT
     USING"##.#####";S
640  I=IO^I
650  LPRINT"INTERCEPT =         ";:LPRINT
     USING"##.#####";I:LPRINT
660  V=I*(CO^S)
670  LPRINT:LPRINT"Ultimate sorption capacity of
     absorbent (mg/K) = ';
680  LPRINT USING"##.####";V*IOOO!:LPRINT
690  GOSUB 820
700  LPRINT "Observed and predicted values of
     log(X/M):
710  LPRINT"Case    Observed    Predicted"
720  FOR I=1 TO T
730  LPRINT USING"## ##.#####
     ##.#####";I,Y(I),P(I)
740  NEXT I: LPRINT
750  LPRINT:LPRINT"Goodness of equation fit (R-
     SQUARE value)          =";
760  LPRINT USING "##.###";RSQ
770  LPRINT******************************************''
780  END
790  :
800  :
810  :
820  REM subroutine to estimate goodness of fit
830  FOR I=1 TO T
840  P(I)=D1/D + S*L(I): REM predicted value
850  AV=AV+Y(I)
860  NEXT I: AV=AV/T: REM AV is average value of
     Y(I)
870  FOR I=1 TO T
880  TS=TS+(Y(I)-AV)-2: ES=ES+(Y(I)-P(I))^2
890  NEXT I
900  RSQ=1-ES/TS: RETURN
```

Table 1 Dirab (Saudi Arabia) Soil Data for Freundlich Isotherms For Sorption of Zinc (Crowe, et. al., 1987).

(14 days of contact)

Soil conc. mg/L	Residual zinc* conc. mg/L	Zinc* Absorbed mg/L	mg/g	mg/g
M	C	X	X/M	or X/M
Blank 0	1.65	0	0	0
250	0.9	75	0 003	3
500	0.47	1.18	0.00236	2.36
1000	0.30	1.35	0.00135	1.35
2000	0.15	1.50	0.00075	0.75
4000	0.12	1.53	0.00038	0 38

*determined by atomic absorption spectrophotometry

Figure 4. Program FREUNDHC results for date in Table 1. Freundlich Adsorption Isotherm

--- Input Data ---

Concn. of Adsorbent mg/L	Contaminant Still in soln, mg/L	Contaminant Adsorbed mg/L	X/M mg/g
250	.9	.75	3
500	.47	1.18	2.36
1000	.3	1.35	1.35
2000	.15	1.5	.75
4000	.12	1.53	.3825

Control value used was 1.65 mg/L

--- Calculations ---

C	log C	log (X/M)	log(C^2)	log C*(log[X/M])
0.900	-0.045758	-2.522879	0.002 94	0.115441
0.470	-0.327902	-2.627088	0.107520	0.861428
0.300	-0.522879	-2.869666	0.273402	1.5000488
0.150	-0.823909	-3.124939	0.678826	2.574664
0.120	-0.920819	-3.417369	0.847909	3.146777

--- Results ---

Using SOIL to remove ZINC(II):
sum of log (C)'s: -2.64127
sum of log (X/M)'s: -14.56194
sum of log C)^2's: 1.90975
sum of (log C * log [X/M]): 8.19880

SLOPE = 0.98429
INTERCEPT= 0.00405

Ultimate sorption capacity of absorbent (mg/g)=6.6318

Observed and predicted values of log (X/M):

Case	Observed	Predicted
1	-2.52288	-2.43748
2	-2.62709	-2.71519
3	-2.86967	-2.90710
4	-3.12494	-3.20340
5	-3.41737	-3.29879

Goodness of equation fit (R-SQUARE value)=0.931

centration. This represents the ultimate sorption capacity of the adsorbent for that contaminant (Rowe, et. al., 1987).

The Freundlich equation is most useful for dilute solutions over small concentration ranges. The $1/n$ value represents the slope or change in rate of effectiveness in uptake with varying amounts of adsorbent, and K, the ordinate intercept, the fundamental effectiveness of the adsorbent. High K and $1/n$ values indicate high adsorption capacities; low $1/n$ values or a steep slope indicate high adsorption at high contaminant levels and low adsorption at low contaminant levels (Rowe and Johnston, 1978).

Both graphical and computer analysis can be made for the Freundlich Adsorption Isotherm. The objective of this study is to select one of the ten metals regulated in Subpart B of the 503 regulations and compare the two analysis methods relative to environmental accumulation. The ten metals are arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc (Sieger and Hermann, 1993). Because of its ubiquitous nature and ease of analysis, zinc was chosen for this investigation.

Table 1 presents the adsorption or sorption data for zinc by Dirab (Saudi Arabia) soil after 14 days of contact, using a continuously agitated slurry technique. Figure 2 is a plot of these data (Rowe, et. al., 1987).

Thus the top 1 cm of soil would have a capacity of 26,000 g x 0.95 mg/gram = 24,700 mg of zinc.

or 24,700 mg = 107,391 L

0.23 mg/L

= 107 m³

An application rate of l m water per m² soil area per year would require 107 years to saturate the top 1 cm of soil with zinc.

Modern wastewater treatment facilities possess the equipment and trained staff to perform analyses such as those in this discussion. Each program has its own unique sludge and soil characteristics, and the higher metal concentrations contained in processed sludge require site-specific analysis. But this technique is another tool that gives an understanding of their compliance with the new Part 503 standards.

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The Effect of Chlorination and Ozonation on The Formation of Disinfection By-Products

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The Palm Beach County Water Utilities Department (PBCWUD) owns and operates a 16 mgd lime softening/filtration WTP treating groundwater from the surficial aquifer. Ozone is added between softening and filtration to reduce finished water color to below 10 cu. Disinfection is accomplished through chloramination.

A investigation was conducted of different chlorination and ozonation treatment operating scenarios and the resulting effects on disinfection by-product (DBP) formation. The different operating scenarios tested were also designed to investigate how future regulations, such as the DBP Rule and the GWTR, will impact WTP operation.

Operating Scenarios

The different treatment scenarios varied the dosage and location of chlorine addition and the dosage of ozone. Common goals for all the operating scenarios were to maintain finished water color below 10 cu and meet DBP levels as proposed in upcoming regulations. Each of the three scenarios were designed for separate objectives: • Scenario 1: minimize ozone dosage by using chlorine for pre-oxidation, • Scenario 2: minimize chlorinated disinfection by-products, and • Scenario 3: maintain a chlorine residual through the ozone basin for disinfection credit. Table 1 lists the operating parameters for each scenario. The ozone dosage was divided among the first three chambers of the four chamber ozone contact basin. Figure 1 is a process flow schematic of WTP No. 8 showing the process units, chlorine addition points, and the ammonia addition point.
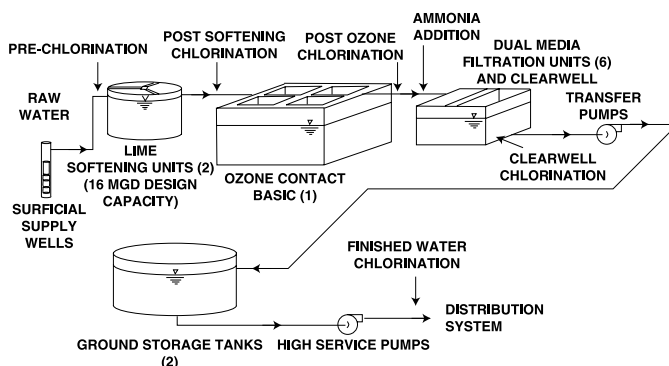

Figure 1. Process Schematic

Figure 2. Trihalomethanes and Haloacetic Acids Results

Table 1. Alternate WTP No. 8 Operating Scenarios

Parameter	Scenario 1	Scenario 2	Scenario 3
Flow, mgd	9.7	10.3	9.5
Ozone Basin Nominal Detention Time, min	32	30	33
Chlorine Dose, Softened Water, ppm	8.1	0.0	22.2
Ozone Dose, Softened Water, ppm	4.0	8.0	4.0
Chlorine Dose, Ozonated Water, ppm	8.1	9.0	0.0
Ammonia Dose, Ozonated Water, ppm	0.6	0.7	0.6

Testing Results

The softened water, ozonated water, and filtered water were all sampled for color and the ozonated water and the filtered water were also sampled for trihalomethanes (THMs), haloacetic acids (HAAs), color, chlorite, chlorate, aldehydes, and bromate. None of the samples showed any detectable amounts of bromate. The aldehydes samples were all less than 65 ppb. Ozone residual was not detected in the ozone basin
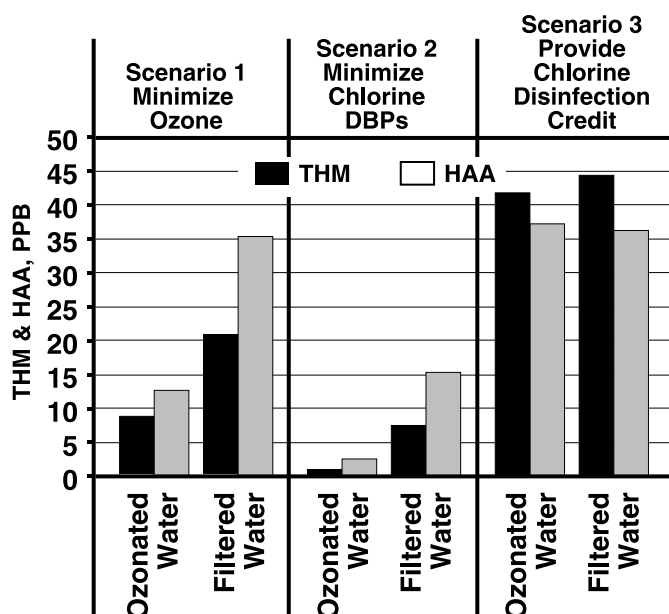
throughout the three scenarios. Figures 2 through 4 show the results of trihalomethanes (THMs), haloacetic acids (HAAs), color, chlorite, and chlorate sampling.

In Scenario 1 chlorine was added between the softeners and the ozone basin to minimize the use of ozone, while still producing a filtered water color less than 10 cu and still meeting current DBP regulations. This models current WTP operation. The concept is that the chlorination prior to ozone reduces the oxidant demand in the water. Because there is less oxidant demand in the water as it enters the ozone basin, less ozone is needed to reduce the color. The chlorine added upstream of the ozone contractor is not intended to achieve any chlorine residual, although in this test run a combined chlorine residual of 1.4 ppm was detected in the ozone basin effluent. Chlorine is added again after the ozone basin, along with ammonia, for a finished water combined chlorine residual of 4.4 ppm.

As expected, the color was reduced to 5 cu in the filtered water. THMs and HAAs were found at 21 ppb and 36 ppb, respectively. The THM result was below the projected Phase 2
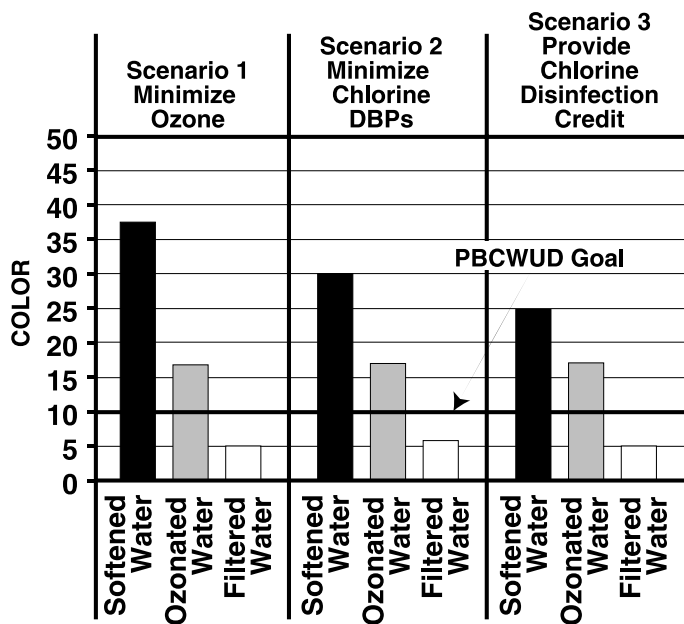
Figure 3. Color Results

Figure 4. Chlorite and Chlorate Results

limit of the upcoming DBP rule, but the HAA result was slightly higher than the projected Phase 2 limit, although below the projected Phase 1 limit. Previous sampling work indicated that the distribution system average of HAA was 29 ppm, slightly less than the projected Phase 2 limit of 30 ppm when operating with pre-ozone chlorination. Chlorite and chlorate levels were found to be 0.08 ppm and 0.02 ppm in the filtered water. The chlorite level was less than the projected limit range for chlorite of 1.0 ppm to 0.1 ppm.

In Scenario 2, the goal was to minimize the formation of chlorine DBPs by not using chlorine prior to the ozone basin and increasing the ozone dosage. Chlorine is added after ozonation and combined with ammonia to form the chloramine residual in the finished water. In this test run the filtered water combined chlorine residual was 4.6 ppm.

The results of Scenario 2 showed that this type of operation minimized DBP formation and reduced the finished water color to 6 cu. THMs and HAAs were found at 15 ppb and 8 ppb, respectively, well below the projected DBP rule Phase 2 limits. Chlorate was not detected in the filtered water and chlorite was 0.02 ppm, below the projected limit range for chlorite.

Scenario 3 was devised to provide disinfection contact time to meet the upcoming GWTR by using chlorine, both free and combined, as the primary disinfectant. By adding chlorine prior to the ozone basin and maintaining a chlorine residual, the ozone basin would act as a chlorine contact tank. In this scenario, all the chlorine was added prior to ozonation, ozone was added at the current plant dose of 4.0 ppm, and ammonia was added after ozonation. A chlorine residual of 1.4 ppm free, 4.8 ppm total, was found in the ozone basin influent. Some free chlorine residual was still found at the end of the first, second, and third chambers of the ozone basin in decreasing concentrations, but the ozone basin effluent chlorine residual of 3.4 ppm was all in the form of combined chlorine.

As with the other scenarios, the filtered water color was reduced below 10 cu to a level of 5 cu. The levels of THMs and HAAs were 45 ppb and 35 ppb, respectively, which are slightly greater than the Phase 2 limits in the DBP rule (40 ppb for THMs and 30 ppb for HAAs). The chlorite level of 0.09 ppm was
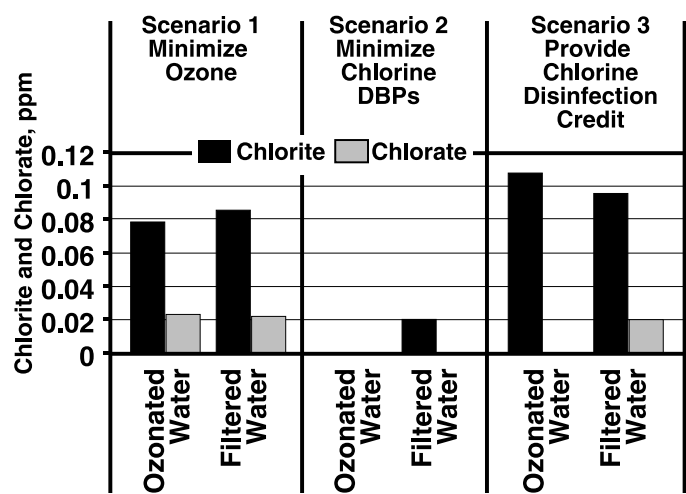
higher than any other scenario but still less than the projected limit range for chlorite. Chlorate was detected at 0.02 ppm.

Conclusions

The investigation showed that the present treatment process at WTP No. 8, lime softening and filtration with ozone for color reduction and chloramination for disinfection can meet all the projected requirements of the Phase 2 DBP rule without modifications to the existing facilities. The amount of pre-chlorine added to the treatment process will determine the necessary ozone dose to meet color goals and the amount of DBPs formed. The higher the pre-chlorine dosage, the lower the required ozone dose but the greater the DBP formation and vice versa.

Besides the DBP rule, the next major drinking water regulation to affect the operation of WTP No. 8 is the GWTR. The GWTR will require disinfection contact time for ground water plants similar to what is currently required for surface water plants under the SWTR, although it will likely be less stringent. Ground water plants will likely be required to show inactivation of viruses similar to the virus inactivation requirements of the SWTR, but not the inactivation of *Giardia* or *Cryptospridium*. Using the SWTR as a model, WTP No. 8 would need to provide a 4-log inactivation of viruses. The use of lime softening and filtration provides a 2-log credit towards the 4-log inactivation requirement. Therefore, WTP No. 8 would likely need to achieve a 2-log inactivation of viruses through chemical disinfection. Maintaining a chlorine or ozone residual in the ozone basin and using that towards meeting future disinfection requirements may be beneficial when investigating possible GWTR requirements.

Two of the three scenarios investigated included maintaining a chlorine residual through the ozone basin, ranging from 1.4 ppm of only combined chlorine (Scenario 1) to 3.4 ppm of total chlorine with decreasing concentrations of free chlorine through the ozone basin, 1.4 ppm at the influent, 0.6 ppm at the beginning of the third chamber, and trace amounts at the effluent of the basin (Scenario 3). Maintaining only a combined chlorine residual through the ozone basin, even as high as 5.0 ppm, would not achieve even a 1-log inactivation of viruses when using the current SWTR guidelines. Conversely, at a water temperature of 20°C, having 0.5 ppm of free chlorine residual at least through one chamber of the ozone basin

Alternative Disinfectants for Hydrogen Sulfide Oxidation and Disinfection

David Baar, Tim Brodeur, Andre Dieffenthaller, and Brad Jewell

he city of Kissimmee is expanding its North Bermuda Water Treatment Plant to meet increasing demands in the service area. Sverdrup Civil, Inc., and Malcolm Pirnie are working together on the design. An evaluation was recently completed to incorporate any necessary changes in the proposed process design to meet existing and future SDWA requirements. One change in the process was to include chlorine oxidation for hydrogen sulfide removal, and thus to replace the existing cascade aeration process and gas chlorination system. This process change was recommended based on the results of field testing for hydrogen sulfide and the following discussions. Field testing of raw well water indicated hydrogen sulfide levels of 0.8 - 1.0 ppm. Ozone was recommended as a long term treatment strategy if new SWDA rules, such as the Disinfectant/Disinfection By-Product Rule, require more extensive treatment and control of disinfection by-products.

The choice of chemicals for chlorine oxication at Kissimmee is either chlorine gas or sodium hypochlorite. The purpose of this study was to evaluate these oxidants and identify the most appropriate one to be used at the North Bermuda WTP. The evaluation considered the following for chlorine gas and sodium hypochlorite:

Safety and OSHA requirements

Estimated capital and chemical costs

Other concerns such as availability and by-products

Safety

Chlorine under atmospheric conditions is a gas that is heavier than air, extremely toxic, and highly corrosive in moist atmospheres. Chlorine gas is irritating to the nasal membranes, and heavy exposure can be fatal. Saftey features required for chlorine facilities design are included in DEP regulations and the Ten States' Recommended Standards for Water Works.

Operators must be adequately trained in the use of self-contained breathing equipment, methods for detecting hazards, and emergency operations. The best protection against accidents is to develop and implement preventive maintenance on the chlorinators, evaporators, and 1-ton cylinder storage containers.

In 1988 considerable changes went into effect on chlorine storage. The May 1988 Edition of the "Uniform Fire Code" (Article 80) required that total containment gas storage rooms be equipped with an exhaust ventilation system adequate to handle the entire contents of the largest single tank or cylinder of chlorine stored. Handling constitutes negative pressure containment in relation to the surrounding area and chlorine neutralization down to 15 ppm at the point of discharge to the atmosphere.

When a vacuum feed system is used, the potential for leaks is usually limited to the components handling the liquid chlorine and gaseous chlorine under pressure. This includes the containers, piping from the containers to the evaporators, the evaporators, and piping from the evaporators to the vacuum regulating valve. Liquid chlorine will adsorb heat from the air and any surface it contacts. The heated liquid will evaporate, thus chlorine leaks will always require containment as a gas.

Exposure of the neighboring communities to chlorine gas in the event of a leak can be minimized with the use of chlorine gas scrubbers. A scrubber can be used to remove the chlorine gas from the exhaust air prior to discharge to the atmosphere. A chlorine monitor sampling the air will automatically activate the scrubbing system in case of a leak. The capacity of the scrubber needs to be great enough to establish a slight negative pressure in the room to prevent leakage to the outside and to remove a selected amount of chlorine gas.

While the city of Kissimmee does not now have containment and scrubbing facilities for its existing gas chlorination system, any expansion or modification requiring a building permit will subject the city to the new safety provisions. Thus gas containment and scrubbing have to be considered part of the components for a new chlorine gas facility.

Alternatively, the use of sodium hypochlorite for disinfection is becoming an attractive alternative for small and large water systems as safety concerns and regulations for toxic chemicals become more stringent. This is especially important for Kissimmee, which has major roadways, ball parks, and residential areas adjacent to the Bermuda WTP and other WTPs.

Sodium hypochlorite is produced in a liquid form, and although the quantity handled is much greater, handling and storage is easier and much safer than for gaseous chlorine. Sodium hypochlorite can be either purchased from chemical suppliers or generated on-site by combining chlorine and sodium hydroxide.

Drawbacks of on-site generation of sodium hypochlorite by this method are high energy requirements and the use of chlorine gas, which eliminates the safety advantage of using sodium hypochlorite. Sodium hypochlorite can also be produced on-site by electrolysis of brine, which eliminates the use of chlorine gas. The process is energy intensive and corrosion can be problematic. Hypochlorite generated on-site is apt to be less pure and more corrosive than hypochlorite generated by manufacturers who specialize in the process. This evaluation assumes 15 percent sodium hypochlorite solution will be purchased from a chemical supplier.

Sodium hypochlorite does not present the hazards associated with chlorine gas; however, it is a corrosive chemical and several preventative and safety measures are recommended in designing sodium hypochlorite feed systems, namely:

• Adequate containment should be provided around storage and day tanks to contain spills or overflows.

• Sodium hypochlorite systems should be placed in a well ventilated room, which should not be used to handle or store other chemicals.

• Sodium hypochlorite causes damage to the eyes and skin upon contact and should be handled with care.

• Sodium hypochlorite is corrosive as a liquid and vapor. Materials and equipment resistant to hypochlorite corrosion are available, and particular care must be exercised in choosing and applying them. Linings, toppings, coatings, pumps, etc., which provide long, relatively trouble free operation, can be provided.

Other Concerns/Benefits

Storage: All sodium hypochlorite solutions are unstable and deteriorate with time. Under the conditions of sodium hypochlorite stock solution storage, the primary decomposition product is chlorate. A minor side reaction produces oxygen. Factors influencing sodium hypochlorite stability are: temperature, light, solution strength, and impurities. Freshly prepared sodium hypochlorite is desirable, and a storage time of two weeks or less is recommended for Kissimmee. While this increases the frequency of delivery and operator attention, the solution decomposition to the chlorate will be miminized.

Disinfection By-Products: The chlorate formation may be a concern for sodium hypochlorite use because this is the primary hypochlorite decomposition pathway. Chlorate formation is highly dependent on time and temperature of sodium hypochlorite storage. Increasing storage time and temperature increases the chlorate concentration. Therefore, depending on the initial chlorate concentrations in the solution, the storage time, temperature, and dosage, chlorate may present a health threat in the future. However, determination of relevance of chlorate levels is difficult at this time.

Currently, chlorate is not a regulated compound, and the proposed D/DBP rule provides no provision for regulation. Nevertheless, EPA has studies regarding the health risks associated with chlorate in progress, and these studie should be monitored. The intent is to regulate chlorate in Stage II of the D/DBP rule (after Year 2000). Therefore, if Kissimmee selects hypochlorite as the oxidant, this will need to be re-evaluated once this rule is more clearly defined. Potential problems, however, can be mitigated by minimizing the storage time to reduce chlorate formation.

Benefit-pH Increase: Sodium hypochlorite is a basic solution and at the dosages required for Kissimmee's process, the pH will be raised from 7.8 to 8.2. This increase in pH is beneficial for reducing the corrosivity to copper. Even though the Kissimmee Bermuda water service area did not exceed the action levels for copper (2.3 mg/l), there were high copper values (>1.5 mg/l). Thence, raising the pH is prudent to minimize copper solubility, and this recommendation had been made earlier in the Water Quality Master Plan (Malcolm Pirnie, 1992).

Benefit-One Chemical Replaces Two: The use of sodium hypochlorite replaces the use of both chlorine gas and sodium hydroxide (caustic soda for pH adjustment). One chemical makes for a simpler design and is easier to control.

Availability: Sodium hypochlorite is readily available in the area and can be delivered every week or two. The local supplier generates the sodium hypochlorite and has three other distributors in the state of Florida, with their main facility in Kentucky. Therefore, if a natural disaster such as a hurricane limits deliveries from the local distributor, other supply sources are available. In addition, the local supplier does have an emergency response procedure during natural disasters.

Opinion of Probable Costs

A present worth analysis was completed for the two oxidation systems and based on all capital expenses occurring in the first phase of construction. Most of the improvements for the chlorine gas facility will have to be completed in the first phase, and even though the liquid chemical feed systems can be phased by initially using smaller metering pumps and bulk storage to satisfy the first phase requirements, the difference in costs will not have a significant impact on the analysis. Chemical costs were not escalated during the anaylsis because chemical costs tend to fluctuate and are difficult to predict, thus costs were assumed to remain constant. Present worth costs are based on a 20 year evaluation at 8 percent interest.

Chlorine gas capital costs include the chlorinators, emergency scrubber, building, and major safety equipment. Because chlorine gas acts as an acid and decreased the pH, and the sodium hypochlorite acts as abase and increases the pH, costs for sodium hydroxide were added only to the chlorine gas costs. pH adjustment to approximately 8.0 is necessary at the Bermuda WTP in accordance with a recent corrosion control study. The present operation at the Bermuda WTP lowers the pH form 8.1 to approximately 7.5 with chlorine gas addition. During bench scale tests using sodium hypochlorite, the pH increased to approximately 8.2 which demonstrated that pH adjustment may not be necessary if sodium hypochlorite is used instead of chlorine gas.

Sodium hypochlorite and sodium hydroxide costs include the bulk storage and containment, chemical feed and transfer pumps, day tanks, and safety equipment. Building costs were not included for hypochlorite or hydroxide since day tank rooms are included in the construction of the new administration/pump room building.

The chemical costs for chlorine gas ($438/ton cylinder) and sodium hypochlorite ($0.80/gal.) are based on Kissimmee's current price for ton cylinders and an estimate from the same chlorine supplier for the sodium hypochlorite. Sodium hypochlorite costs ($220/dry ton) are based on recent chemical costs for the area. Chemical costs are expected to fluctuate for both chlorine gas and sodium hypochlorite at the same ratio. However, fluctuations in chemical costs over the life of the project can be ignored and were not considered in this analysis because these chemicals tend to be interrelated (sodium hypochlorite is generated by chlorine gas and sodium hydroxide, chlorine gas tends to decrease as hydroxide costs increase, and sodium hypochlorite is required if chlorine gas is used of pH adjustment).

The following table summarizes the capital and chemical costs and present worth value of each alternative:

Opinion of Probable Costs Summary

Chemical System	Capital Cost ($)	Chemical (c/1000 gal.)	Total Present Worth ($)
Chlorine Gas & Sodium Hydroxide (ton cylinders)	$793,500	1.8	$1,320,000
Sodium Hypochlorite	$209,500	3.2	$1,150,000

Summary

Both chlorine gas and sodium hypochlorite are similar in their effectiveness in regard to oxidation and disinfection. The main differences with the two are the safety issues and the costs. Chlorine gas can cause severe health effects in the event of an uncontrolled gas discharge. Sodium hypochlorite use and storage do not present the hazard that chlorine does, and scrubbing facilities would not be required. Sodium hypochlorite does deteriorate over time with increasing temperatures. Therefore, storage times are recommended to be less than two weeks for Kissimmee. The total opinion of probable present worth costs for chlorine gas and sodium hypochlorite facilities are $1,320,000 and $1,150,000, which shows hypochlorite may be more cost effective based on a 20-year analysis. The chlorine gas costs include a sodium hydroxide facility because pH adjustment will be necessary to increase the pH after chlorine gas addition.

Chlorine gas is an economical means of disinfection, and one in which the city has knowledge and history in its use. However, even though hypochlorite is a chemical with which the city is unfamiliar, the proximity of ballparks, major roadways and residential communities to the WTP and the requirement for increased chlorine use and storage dictate that consideration of safety factors is essential. Many large water treatment plant facilities are modifying their facilities to sodium hypochlorite for this reason including one of New York City's disinfection facilities (1.5 billion gallons per day). Further, with hypochlorite the city will only have to add one chemical for disinfection. With chlorine gas, two chemicals are needed, chlorine plus sodium hyrdoxide. Although slight, the risk of a serious gas discharge will be present. Therefore, the operational advantage of expanding and upgrading the chlorine gas facilities must be considered against the potential hazard of increased chlorine gas and storage.

The city of Kissimmee approved the design of using one chemical, sodium hypochlorite, in lieu of two chemicals, gas chlorine and sodium hydroxide. Sverdrup and Malcolm Pirnie are currently proceeding with final design of the water treatment plant. Construction of the improvements is scheduled to start February 8, 1996, and start-up is anticipated December 8, 1996. A follow up article will be presented after the new facility has operated for a six month period to review actual operational experience.

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Chlorination and Ozonation from Page 36

would provide 2-log inactivation of viruses. This, in combination with the 2-log inactivation of viruses provided by the conventional treatment of lime softening and filtration, would provide WTP No. 8 with the required 4-log inactivation of viruses.

Having free chlorine residual in the ozone basin will cause the formation of DBPs. The results of this investigation showed that, when a free chlorine residual is maintained throughout the entire ozone basin, THMs and HAAs are formed greater than the projected Phase 2 limits of the DBP rule (Scenario 3). Reducing the free chlorine contact time to only the first chamber would reduce the amount of DBPs formed. Since the amount of THMs and HAAs formed in Scenario 3 were each only 5 ppb greater than the projected regulatory limits with free chlorine residual held throughout the entire ozone basin, reducing the contact time of the free chlorine to only one chamber leads to the reasonable assumption that the DBPs will be reduced by at least 5 ppb, thereby meeting even the Phase 2 DBP limits on THMs and HAAs.

Using ozone as the disinfectant, previous work had determined that a dose of 15 to 20 ppm would be required to produce an ozone residual. This amount of ozone needed would require a considerable increase in the capacity of the plant ozonation system, which is a significant capital cost.

Recommendations

Based on the work in this study, the existing treatment system apparently can not only meet the requirements of the DBP Rule, both Phase 1 and Phase 2, but, with some minor modifications, can meet the likely requirements of the GWTR. To verify this conclusion, Scenario 4 should be run with ammonia added in the first chamber of the ozone basin instead of after the basin to shorten the free chlorine contact time. A second alternate which should be investigated is to add chlorine point at the beginning of chamber 4 of the basin with the ammonia being added at the current injection point at the outlet of the ozone basin. Determination of the actual basin detention time through tracer studies is also recommended. Of course, meeting the GWTR could also be accomplished through other means such as adequate detention time for finished water chloramine contact/disinfection.

Francis E. Duran, P.E., and Glenn Dunkelberger, P.E., are engineers with Montgomery Watson, Plantation. Eugenia Carey is laboratory director, Palm Beach County Water Utilities Department.