Distribution System Water Quality Models Support Treatment Process Decisions

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The U.S Environmental Protection Agency (EPA) has estimated that over 260 million individuals in the country are exposed to disinfectant/disinfection byproducts (D/DBPs). The Stage 2 D/DBP Rule was implemented by EPA to regulate D/DBPs to within standards for human health, without increasing the risk of microbial contamination. In advance of the rule, the Seminole County Environmental Services Department (SCESD) proactively addressed areas with potential compliance issues to provide its customers with continued water quality excellence.

The SCESD identified the need to further treat source waters to reduce D/DBP formation in one of its service areas to ensure compliance with the Stage 2 D/DBP Rule. When designing any new enhanced treatment processes, the type and amount of treatment necessary must be identified. Water quality models were utilized by SCESD to measure and compare different treatment processes available, as well as identify the optimal treatment blending ratios. The blending analysis identified the amount of water required for enhanced treatment to potentially reduce the treatment equipment footprint and cost. This article discusses the innovative approach of utilizing a water quality model to predict system chlorine residuals and D/DBPs based on pilot tested results for several different enhanced water treatment processes to comply with the Stage 2 D/DBP Rule.

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Pilot-scale treatment studies were performed at existing water treatment plants (WTPs) to support treatment alternative evaluations and recommendations to fulfill Stage 2 D/DBP Rule requirements. Alternate treatment options, including ozonation, granular activated carbon (GAC), biological activated carbon (BAC), ion exchange with MIEX®, and reverse osmosis were considered. Based on the D/DBP formation and chlorine decay corresponding to each process evaluated during the pilot study, coefficients of D/DBP formation and chlorine decay were developed.

The resulting D/DBP formation and chlorine decay coefficients were entered into the wa-ter quality models for different alternatives, such as ozone (O_3) followed by GAC. The primary DBPs, trihalomethanes (THMs), and haloacetic acids (HAAs) were simulated and predicted at monitoring locations throughout the distribution system to confirm that the level of treatment would be acceptable to meet Stage 2 D/DBP Rule requirements. The water quality model simulation results were used to assist SCESD and the WTP design team in making decisions related to the level and methods of treatment, in addition to respective cost of each service areas treatment alternatives to comply with Stage 2 D/DBP Rule requirements.

Project Purpose

The overall goal of the project was to develop successful water treatment alternatives to achieve Stage 2 D/DBP Rule compliance at the established monitoring locations and throughout the entire distribution system during existing and future operational scenarios. The plan to accomplish this goal was to:

1. Review different treatment processes and options that align with established goals.
2. Select treatment processes for pilot testing.
3. Assess design parameters with each process.
4. Pilot-test processes to determine design criteria and capacity requirements.
5. Develop advanced water quality hydraulic model to predict THM/HAA formation in a distribution system.
6. Perform various model evaluations for future potential operational scenarios.
7. Develop viable treatment alternatives (footprint, capital cost, operation and maintenance costs, pros/cons).
8. Recommend proposed alternatives.

Model Development

When developing a water quality hydraulic model it is important to create as accurate a representation of the system as possible prior to running any simulations. Many existing created models were initially only used for hydraulic purposes and typically need significant modifications in order to simulate water quality. Additionally, similar to a geographic information system (GIS), if the model does not receive regular updates of information its value can diminish. As a model becomes more and more out of date, confidence in the model will decline.

However, modeling software advances have made the transfer of data almost automatic, making model updates much less labor intensive. For this project, it was important to create an accurate representation of the SCESD system in order to estimate future water quality within the distribution system for Stage 2 D/DBP Rule compliance. Results of the model simulations, pilot data, and field sampling were all used to make decisions of the type and amount of treatment upgrades needed, which would result in multimillion dollar upgrades to a WTP. The following actions were used to create the SCESD water quality hydraulic model:

- Perform and update model components:
  - Structurally (pipe, junctions, pumps, tanks, and valves)
  - Demand
  - Scenario management
- Perform a hydraulic and water quality calibration:
  - Hydraulics
    - At point-of-entry locations (WTPs)
    - At hydrant-field-recorded pressure locations
  - Water quality (CL2, fluoride/water age, THM, HAA)
- Utilize the calibrated model to assist with treatment level decision making and compliance with Stage 2 D/DBP Rule

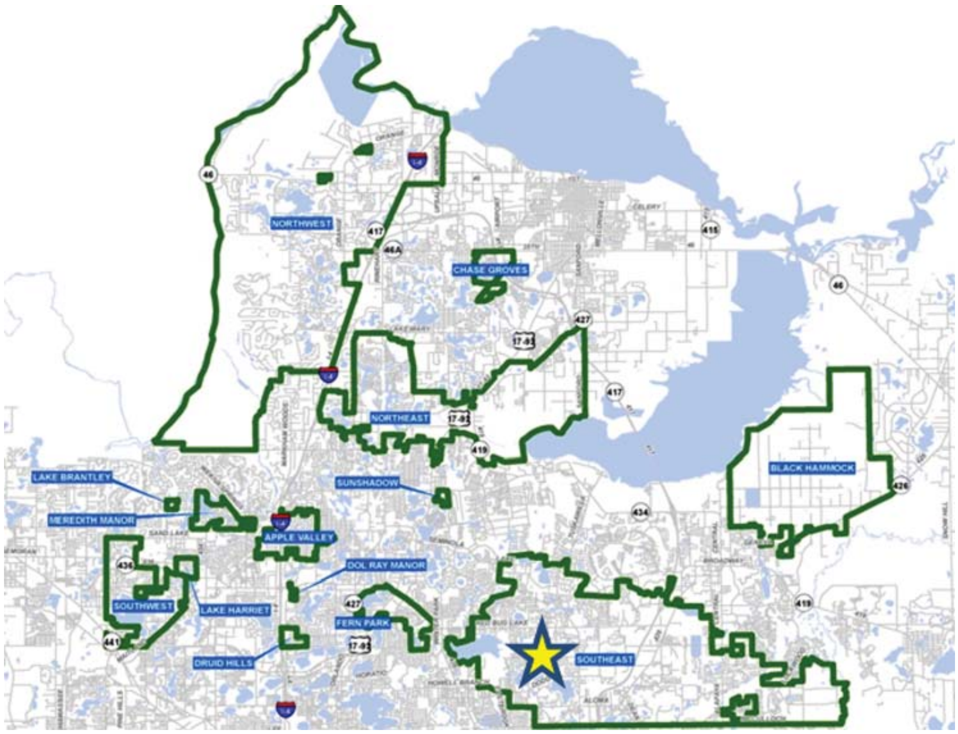

Figure 1. Seminole County Environmental Services Department Service Areas

Figure 2. Facility Update Utilizing As-Built Drawings

Model Components Update

The latest SCESD system component information was utilized and compared to the

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existing model for accuracy. The model demands were updated based on demand data collected in 2011-2012. Separate data sets for existing and future demands were generated for the scenarios and extended period simulation (EPS) scenarios were also created to enable water quality modeling capabilities.

Structural Update

Structural components, including pipes, pumps, groundwater storage tanks, water supply sources, and junction elevations were updated in the hydraulic model from information collected from SCESD. Differences between the GIS data and hydraulic model data were identified and updated. The hydraulic model structural components were also integrated with GIS. Integration utilizing a unique identification provides SCESD with the ability to more efficiently update model components from the GIS information. Additional modifications to facility control operations and the decommissioning of water facilities were incorporated for future hydraulic simulations. Expansion of the water facilities, which included the addition of future high-service pumps, was also incorporated into the hydraulic model. The model was updated to include all current system information, including recently constructed transmission mains and future water mains.

Figure 3. Demand Allocation

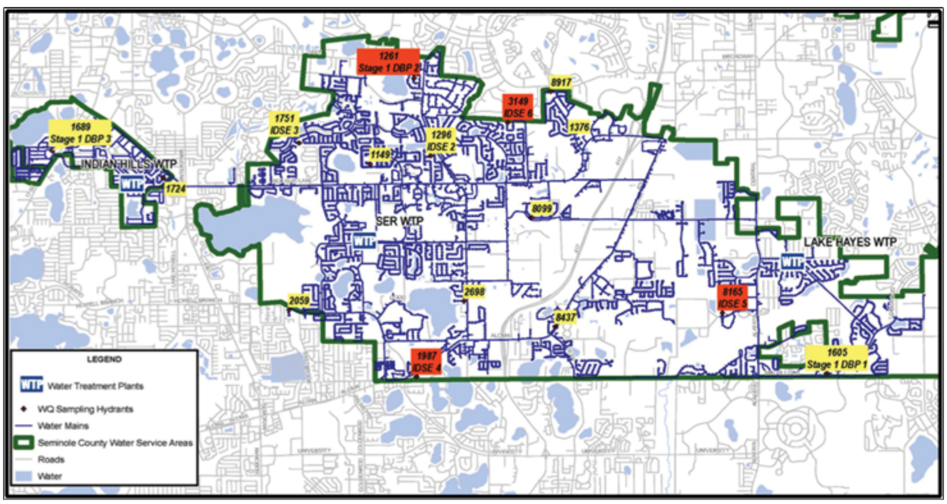

Figure 4. Field Sampling Locations

Demand Update

One year of historical water meter billing information was converted into geocoded demands and allocated into the hydraulic model junctions. A yearly average, in gal per minute (gpm), was calculated for each meter location. The geocoding process involved linking the water meter billing data with Seminole County property appraiser GIS parcel data by the unique parcel identification numbers. The water meter billing data was then assigned the associated geographic coordinate from the parcel. Once the water meter billing data had geographic coordinates, the features were mapped and entered into GIS. The geospatial referenced water meter billing data was used to allocate the calculated demand information into the hydraulic model junctions. The demand allocation was done by spatially joining the point demand data to the closest pipe. The demand was then split in a distance-weighted fashion between the two nodes connecting the pipe.

Scenario Management

Hydraulic model scenarios were created to represent steady state and extended period simulations with the updated demand information. Average-day, maximum-day, maximum-day plus fire flow, and peak-hour demand scenarios were created for existing and future build-out conditions. The hydraulic model was updated to include existing and future EPS scenarios with the ability to simulate water age DBP formations, fluoride concentrations, and chlorine residual concentrations. The supervisory control and data acquisition (SCADA) system flow information was used to create a 48-hour diurnal demand pattern based on one normal irrigation and one nonirrigation day. Each of the allocated demands would increase and decrease based on the pattern throughout the selected days.

Model Calibration

Distribution System Field Sampling

A hydraulic and water quality model calibration protocol for obtaining measurements and correlating the measurements with the hydraulic model simulated results was developed. Coordination among supply facilities, operators, and field personnel was required to ensure the system was operated consistently under typical operation, and that standard customer service levels were maintained during the data collection process. Two levels of data collection and calibration were required to increase hydraulic precision that, in turn, proved to increase the models water quality predication accuracy.

The first level of data collection and calibration began at the water facilities point-of-entry locations and included data collection of recent SCADA information such as treatment plant pressures, flows, pump operations, variable frequency drive speeds, tank levels, and discharge chlorine residuals, as well as discharge fluoride, chlorine decay, and DBP formation sampling. Approximately 200,000 hydraulic data points of SCADA information were collected to confirm and calibrate water facility hydraulics in the model for existing conditions.

The second level of data collection and calibration consisted of collecting distribution system hydraulic and water quality data to correlate potential increases from the point-of-entry locations to the selected sampling sites, and more specifically, the Stage 2 D/DBP Rule locations. Field pressure recorders, chlorine residuals, DBPs, and fluoride sampling were collected at the locations shown in Figure 4.

The facility and distribution system data collected for calibration were collected during the same two-week time period in order to increase model-to-field accuracies by having consistent hydraulic and water quality data. Additional field pressure measurements were collected by installing pressure recording instruments at key locations in the distribution system. Approximately 800 chlorine, fluoride, THM, and HAA field samples were collected for the distribution system water quality calibration. The facilities-collected SCADA data identified a two-day pattern that repeated throughout the sampling period, which was used to create a two-day diurnal demand pattern that simulates irrigation and nonirrigation days. Modifications to the models were made based on field-collected pressure, chlorine, THM, and HAA measurements to accurately simulate the existing system conditions in the constructed models. Figures 5 through 10 represent model versus field data calibrated results. As illustrated, the accuracy of the field versus model results exceed the established goal of the Florida Section American Water Works Association (FSAWWA), which is greater than 95 percent accuracy, and it is ready to support SCESD and the design team in making a decision on the type of treatment process and level of treatment necessary to comply with the Stage 2 D/DBP Rule.

Pilot Sampling and Results

In parallel with the water quality hydraulic model structural update, field sampling, and calibration, pilot- and bench-scale testing was performed for the identified treat-

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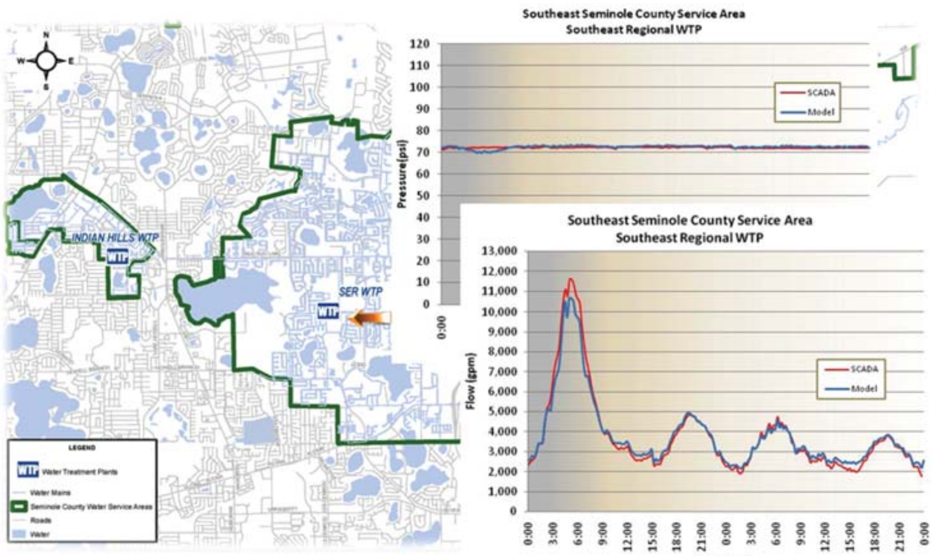

Figure 5. Southeast Regional Water Treatment Plant Field Flows and Pressures Versus Model-Simulated

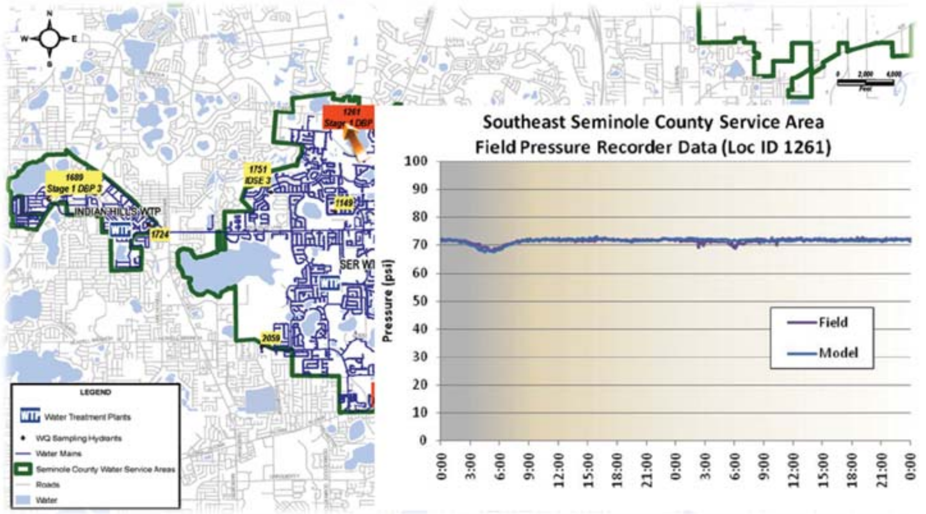

Figure 6. Field-Collected Pressures Versus Model-Simulated

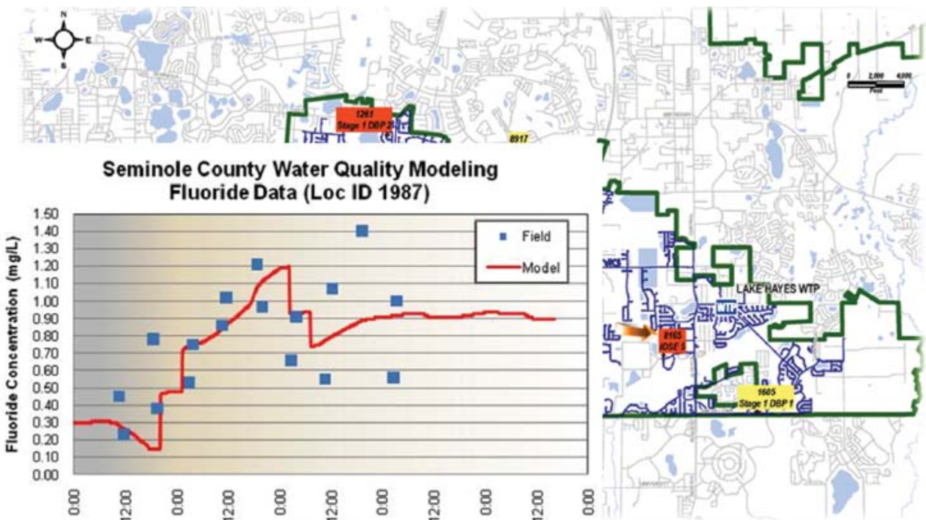

Figure 7. Field-Collected Fluoride Versus Model Simulated

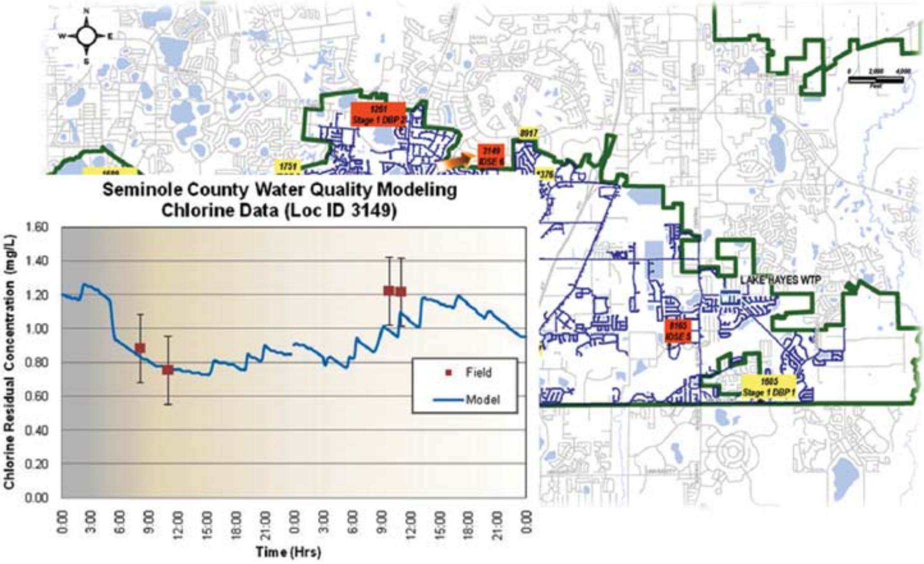

Figure 8. Field-Collected Chlorine Versus Model Simulated

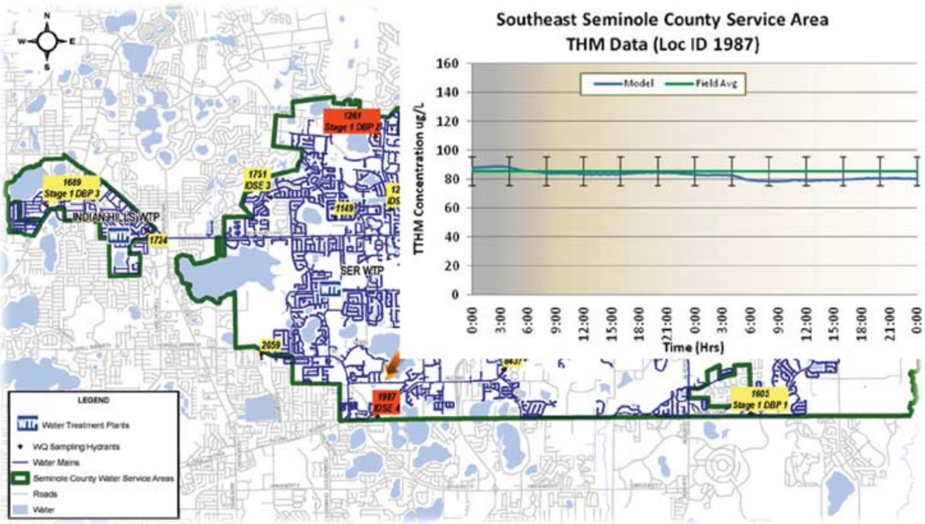

Figure 9. Field-Collected Trihalomethane Versus Model-Simulated

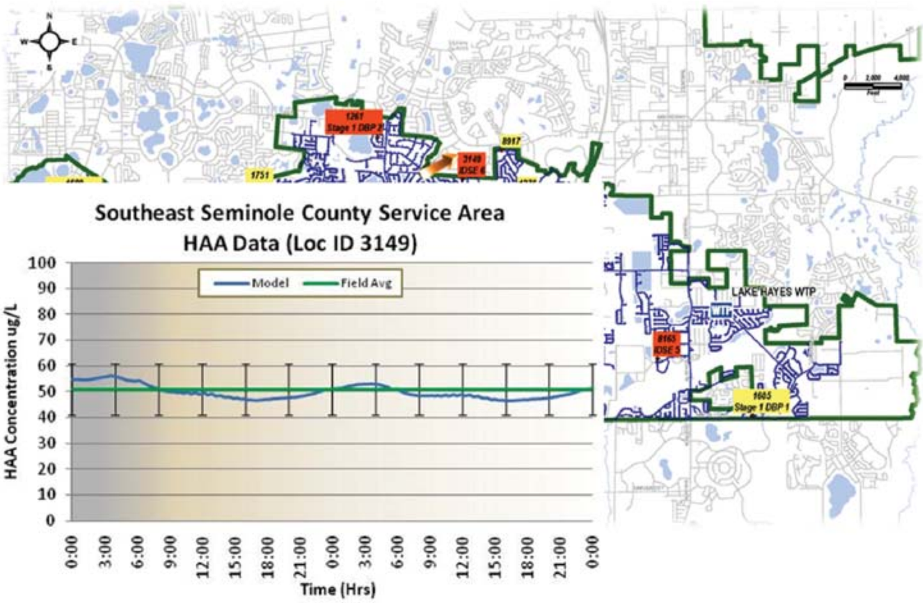

Figure 10. Field Collected Haloacetic Acids Versus Model-Simulated

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ment alternatives. The objectives of the pilot studies were to determine the effectiveness of the treatment options to reduce hydrogen sulfide and organic content. Sulfide levels needed to be reduced to low or undetected levels in order to minimize odor complaints, as well as reduce the chlorine demand. Chlorine is used to oxidize sulfide, which results in an increase in chlorine demand over the required demand for disinfection. The chlorine reaction with total organic carbon (TOC) over time leads to the formation of DBPs. The removal of organics, and hence the removal of DBPs, was also evaluated as part of the study to achieve compliance at the Stage 2 D/DBP Rule locations and throughout the distribution system. The DBP formation potential for the selected treatment options were evaluated to determine the levels of treatment required to meet the following THM/HAA finished water quality goal:

- SCESD distribution water quality goals
  - 60 µg/L THM at Stage 2 locations (water quality goal exceeding Stage 2 D/DBPR limit)
  - 40 µg/L HAA at Stage 2 locations (water quality goal exceeding Stage 2 D/DBPR limit)
- Process configurations assessed during pilot testing
  - Existing treated water
  - Existing treated water plus ozone
  - Ozone
  - GAC
  - Ozone plus GAC
  - Nanofiltration
  - Nanofiltration plus ozone (permeate)
  - Ion exchange

Water quality results from the pilot testing obtained information on total sulfide, chlorine residual, temperature, pH, TOC, Ultraviolet-254, THMs, and HAA. The water quality information obtained was utilized to determine the effectiveness of the combinations of the treatment alternatives to meet the goals and comply with Stage 2 D/DBP Rule regulations. In addition to evaluating the DBP formation on the various treatment effluents, DBP formation was also evaluated on several blended influent and effluent streams. Without these evaluations, only a theoretical extrapolation between source waters constituting the blended streams could be performed, which would not be an accurate evaluation. The DBP formation and chlorine decay potential were evaluated using the following treated water at different levels of blend ratios:

- GAC – Existing treated water blends

- 100 percent GAC filtered
- 75 percent GAC filtered – 25 percent existing treated water blend (no ozone)
- 50 percent GAC filtered – 50 percent existing treated water blend (no ozone)

- NF - O_3 water blends
  - 100 percent NF
  - 75 percent NF – 25 percent existing treated ozonated water blend
  - 50 percent NF – 50 percent existing treated ozonated water blend
  - 25 percent NF – 75 percent existing treated ozonated water blend
- GAC - O_3 water blends
  - 100 percent GAC
  - 75 percent GAC – 25 percent existing treated ozonated water blend
  - 25 percent GAC – 75 percent existing treated ozonated water blend
- GAC - O_3 partial breakthrough water blends
  - 100 percent GAC
  - 75 percent GAC – 25 percent existing treated ozonated water blend
  - 25 percent GAC – 75 percent existing treated ozonated water blend
- GAC - O3 full-breakthrough water blends
  - 100 percent GAC
  - 75 percent GAC – 25 percent existing treated ozonated water blend
  - 25 percent GAC – 75 percent existing treated ozonated water blend

The pilot study data was used to create kinetic formation coefficients (K_b), initial levels of THM and HAA (C_0), and limiting levels of THM and HAA (C_L) for utilization within the hydraulic model. The collected data was plotted and a best-fit line was established as illustrated in Figure 11 and summarized in Table 1, which shows the GAC followed by ozone blended pilot information.

Simulation Results and Conclusions

Approximately 75 different model scenarios were created based on the pilot data and future operational changes established to evaluate the ability of the potential future treatment alternatives to meet the treatment goals and comply with the Stage 2 D/DBP Rule within the distribution system. Simulated model output for the different water quality scenarios and variables were summarized for each of the sampling locations. Table 2 shows four of the locations of the water quality hydraulic model results of the GAC-Ozone scenarios.

The simulation results of the water quality models provided key information used to assist SCESD and the WTP design team in making decisions related to the level and methods of treatment needed to meet SCESD's finished water quality goals. The water quality modeling confirmed specific GAC and ozone treatment capacities for blending, thereby optimizing treatment facilities requirements and cost. The valuable information gleaned from the pilot study, in conjunction with field sampling and water model quality simulations of future conditions, increased the team's confidence level in process decision making and reduced overly conservative assumptions. The water quality modeling projects water quality changes from the treatment plant into the distribution system, where the compliance is measured. The treatment evaluation, coupled with the water quality modeling, indicated that a blended treatment using GAC and ozone resulted in a decrease in THM formation levels at the locations identified within the distribution system and projected compliance with the Stage 2 D/DBP Rule.

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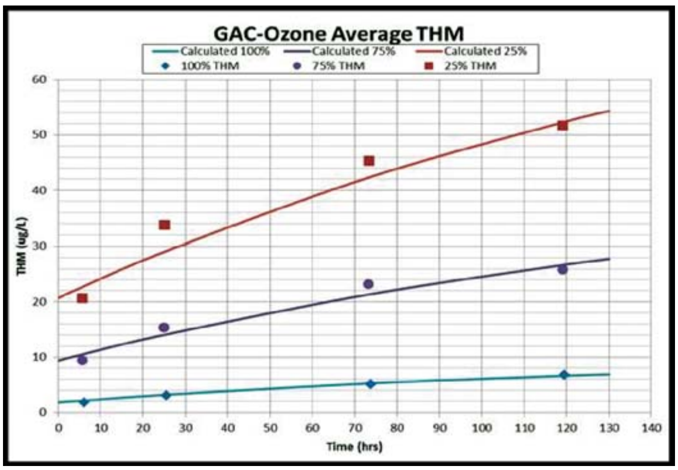

Figure 11. GAC-Ozone Blend Analyzed Data

Table 1. GAC-Ozone Blended Model Inputs

GAC-O_3 Evaluations	Initial THM Concentrations, C_0 (ug/L)	THM Limit Concentrations, C_L (ug/L)	THM Formation Coefficient, K_b (1/day)
100% GAC	2	10	0.196
75% GAC, 25% O_3	9	45	0.147
25% GAC, 75% O_3	21	90	0.135
GAC-O_3 Evaluations	**Initial HAA Concentrations, C_0 (ug/L)**	**HAA Limit Concentrations, C_L (ug/L)**	**HAA Formation Coefficient, K_b (1/day)**
100% GAC	3	15	0.039
75% GAC, 25% O_3	5	20	0.100
25% GAC, 75% O_3	14	55	0.078

Table 2. GAC-Ozone Distribution Model Simulated Results

Location ID	Model Predicted Average THM (ug/L)		
	100% GAC	75% GAC, 25% O_3	25% GAC, 75% O_3
3149	8	23	47
1261	8	27	53
8165	6	23	46
1987	5	17	35