JEA Main Street Water Treatment Plant: A Balance of Treatment, Rehabilitation, Project Delivery, and Cost

Kenneth Blanton, Colin Groff, Brad Vanlandingham, and Cheryl Robitzsch

Kenneth Blanton, P.E., is project manager with Black & Veatch in Jacksonville and Orlando. Colin Groff, P.E., is director—support services with JEA in Jacksonville. Brad Vanlandingham, P.E., is engineering manager with Black & Veatch in Orlando. Cheryl Robitzsch, P.E., is director of design with Haskell in Jacksonville.

Due to deteriorating water quality south of the St. Johns River, JEA embarked on a program to move water from a more abundant water supply north of the river to the south. This program is called the total water management plan (TWMP), with the first stage of the plan to upgrade the Main Street Water Treatment Plant (WTP), shown in aerial view in Figure 1, and the associated Orange Street Reservoir (OSR). The reservoir, on the site of the water plant, was removed from service due to excessive deterioration. This deterioration was attributed to elevated levels of hydrogen sulfide (H_2S) in the groundwater. Through a desktop evaluation that considered several treatment alternatives for the reduction of the H_2S, two of the alternatives were selected for further evaluation that included preliminary design and estimated costs for each. These two alternatives included: (1) packed tower aeration followed by odor control, and (2) in-line ozone oxidation followed by tray aeration. Ozone was the lowest-cost alternative and selected as a means to reduce the H_2S levels in the raw water, thereby allowing tray aeration to be more effective as the final step in the treatment process.

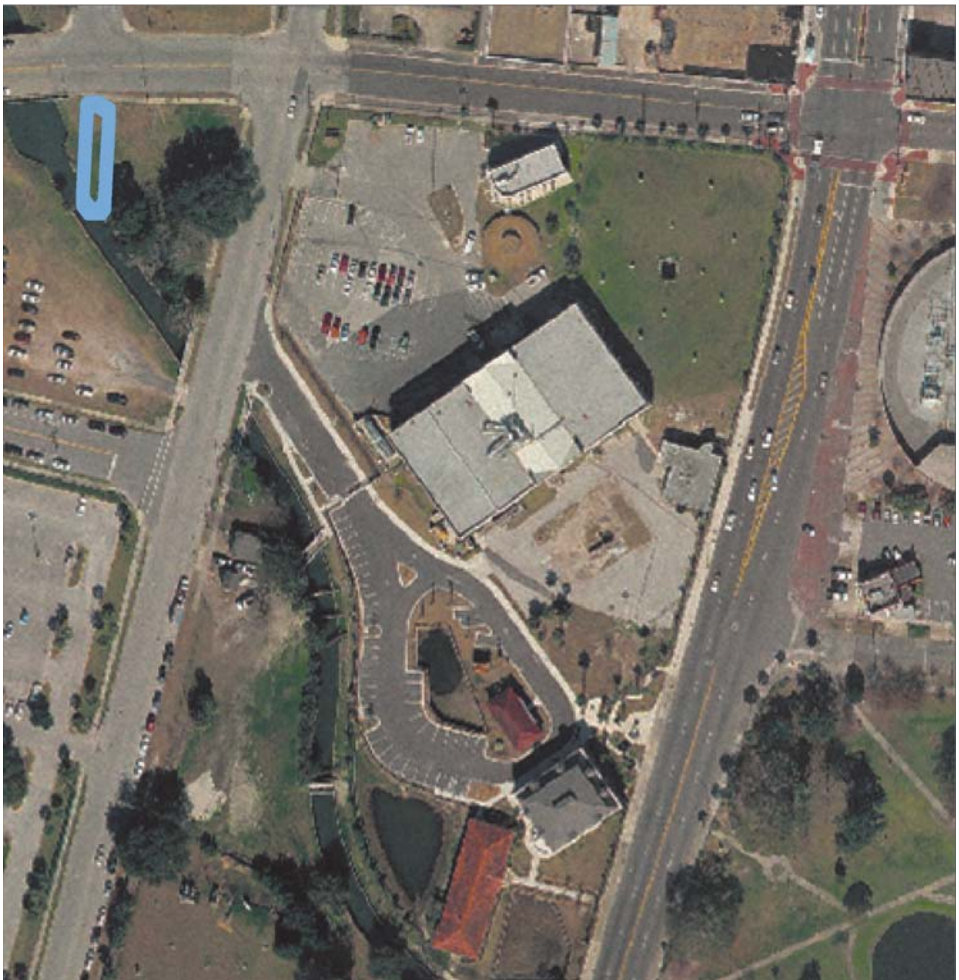

Figure 1. JEA Main Street WTP site description

There were many challenges with the project, including those related to upgrading a facility that is over 100 years old. These challenges include high groundwater table, floodplain encroachment, historical building impacts, contaminated soils, conversion of older buildings to new use, and preservation policies related to the historical significance of the plant.

Because of cost and schedule concerns, JEA elected to deliver this project through a progressive design-build arrangement with a guaranteed maximum price (GMP) established by 60 percent design completion. This contractual arrangement allowed JEA to execute a three-pronged (study, design, and construction) capital project under one contract, with the goal to design and install a new 3-mil-gal (MG) storage tank with combination ozone injection system and tray aeration within 18 months. In addition, JEA desired a collaborative environment to leverage the exchange of ideas among the engineer-of-record, the contractor, and JEA, all in an effort to allow cost savings without sacrificing necessary project elements.

History of the Total Water Management Plan

The JEA drinking water supply comes entirely from groundwater withdrawn from the Floridan Aquifer. The majority of the JEA system is divided into two major service areas: the North Grid and the South Grid. Each grid is served by independent wellfields and interconnected water treatment plants. The North

Grid covers the area west and north of the St. Johns River and the South Grid covers the area east and south of the river.

Within JEA's service area, the Floridan Aquifer is recharged by rainfall and surface water from the central part of the state to the northwest, west, and southwest of Jacksonville. Within the North Grid, which is closest to the recharge area, the aquifer is highly transmissive and a typical production well will yield 2,000 to 3,000 gal per min (gpm) with only a few ft of drawdown. Groundwater withdrawals from the North Grid generally have limited impact on the South Grid since most of the water from North Grid wells is produced from the lower interval of the upper Floridan. As groundwater flow traverses the St. Johns River basin, it is suspected that groundwater leakage into the river reduces the potentiometric head available within the South Grid. This, coupled with less transmissive formations in the South Grid aquifer, reduces the aquifer yield due to significant drawdown impacts and risk of upconing brackish water from deep portions of the aquifer beneath the South Grid.

In 2007, JEA began negotiating a 20-year consumptive use permit (CUP) with St. Johns River Water Management District (SJRWMD). The new permit required JEA to restrict groundwater withdrawals to protect the aquifer below the projected demand in the South Grid potable water distribution system. In response to permit requirements, JEA developed the TWMP, which was the roadmap to meeting future demands by JEA customers on the South Grid. The three main elements of the TWMP included an aggressive reclaimed water program, a measured conservation program, and the major grid transfer improvement project.

The improvement project objective was to transfer 20 mil gal per day (mgd) from the North Grid to the South Grid. This allows the South Grid to reliably reduce its withdrawals to no more than 60 mgd from the aquifer, beginning in 2013. This 60-mgd upper limit or cap, by 2013, is in JEA's CUP, which was issued by the SJRWMD in 2012. In addition, it was important to deliver the 20 mgd to identify points on the South Grid in order to help "spread out" the impacts of withdrawals from existing wellfields in the region.

The two grids are currently interconnected through a 30-in. river crossing pipeline in the downtown area of Jacksonville, supplying approximately 4-mgd flow to the south. But additional interconnection is required to supply water to the southeast in an effort to reduce groundwater withdrawals from the aquifer in specific areas of the South Grid. Based on the proposed large diameter transmission route and proximity to the proposed river crossing, the WTP was considered for providing that "wide spot in the line" to move water from the North Grid to the South Grid.

In addition, the WTP is permitted for 16-mgd average daily flow (ADF) or 24-mgd maximum daily flow (MDF), with current average daily flows averaging 6 mgd. Two additional water treatment plants located in close proximity to the WTP are capable of providing peak demands currently being met by the WTP, with minor system improvements and pressure adjustments. Therefore, the WTP was selected as the starting point of the major grid transfer improvement project pipeline to transfer up to 16 mgd of potable water from the North Grid to the South Grid.

The Main Street Water Treatment Plant

The WTP is rated for 16-mgd ADF and 24-mgd MDF. The MDF is limited by the firm capacity of the eight production wells that supply groundwater to the WTP. Water was previously stored in two on-site below-grade storage tanks: the 3-MG OSR and the 1-MG First Street Reservoir (FSR). The original plant design was based on groundwater pumped into the OSR and then gravity flow to the FSR prior to high service pumping. Sodium hypochlorite is injected into the water for disinfection and maintaining chlorine residual in the distribution system. A phase-one project, completed in June of 2009, included replacement of high service pumps, sodium hypochlorite upgrades, and rehabilitation of the FSR, which suffered from significant and excessive deterioration from H_2S attack. Significant deterioration was also prevalent in the OSR, which was scheduled for rehabilitation and future upgrades in a phase-two project. However, due to the problems and significant expense associated with rehabilitating the 100-year-old FSR, the JEA opted for complete tank replacement of the OSR. A 3-MG circular prestressed concrete tank was selected for the OSR replacement.

Continued on page 40

Table 1. Typical Raw Water Quality Data

Parameter	Units	Well #3	Well #4	Well #7	Well #8	Well #12
pH	S.U.	7.7	7.6	7.7	7.7	7.7
Temperature	°C	26.2	26.2	28.2	28.1	26.1
Turbidity	NTU	0	0	0	0	0
Conductivity	µmhos/cm	595	608	500	528	582
Alkalinity	mg/L as $CaCO_3$	138	135	147	146	138
Total hardness	mg/L as $CaCO_3$	290	304	241	254	286
Calcium	mg/L	73	77	60	63	72
Magnesium	mg/L	26	27	23	24	26
Iron	mg/L	3.7	1.3	1.3	0.8	3.6
Potassium	mg/L	1.9	2.0	1.6	1.7	1.8
Sodium	mg/L	12	12	13	13	12
Chloride	mg/L	15	14	16	16	15
Sulfate	mg/L	151	162	86	104	140
TDS	mg/L	394	426	307	345	433
TOC	mg/L	1.4	1.4	1.8	1.8	1.5

Continued from page 39

The Orange Street Reservoir

The OSR is a 3-MG cast-in-place concrete structure that was built in the early 1900s. The tank foundation was supported by timber piles. To fast-track the schedule, the demolition of the existing structure was identified as an early activity. During preliminary design, the design-build team opted for use of the existing slab foundation as a working, or mud, slab that could be used to support the drill rigs required for geotechnical exploration. In addition, partial walls were left in place to serve as retaining walls during construction. Based on the geotechnical exploration, a grid pattern of 16-in. auger cast piles was developed and installed to support the new prestressed concrete tank. These piles are expected to achieve 75 to 85 tons of allowable pile capacity when embedded 1 to 2 ft into the limestone encountered at approximately 32 ft below ground surface.

Essentially, no load will be carried by the existing wood-pile-supported reservoir foundation. The cost associated with testing the existing wood piles to determine their capacity was found to be high enough that the most economical solution was to ignore the existing pile's capacity and design an independent system. The loading applied by the new tank will be in excess of the load previously applied by the existing tank, and therefore, even if attempts were made to rely on the existing foundation for support, additional piles would almost certainly still be required.

Water Treatment Technology Evaluation

The Floridan Aquifer is one of the world's most productive aquifers, producing consistently high-quality raw water, requiring only minimal treatment before distribution to the public water supply. This aquifer underlies the entire state of Florida and continues to be the primary source for its drinking water. In its natural state, the water in the aquifer is found to have a pH around 7.5-8.0, while temperatures vary between 18°C (64°F) to 27°C (81°F) depending on the season. Locally, the aquifer also contains excess sulfate in the form of H_2S.

Raw water sampling provided sulfide concentrations that ranged from 1.4 mg/L to 2.6 mg/L, enough to impart a foul, objectionable taste and odor that many compare to rotten eggs. The design basis used for the WTP sulfide concentration of the groundwater is 2.6 mg/L. In order to remove the taste and odor associated with the presence of H_2S and to comply with Florida Department of Environmental Protection (FDEP) Chapter 62-555.315(5)(a)-Total Sulfide Treatment Recommendations, the target sulfide concentration of 0.3 mg/L was established. This is the level acceptable for treatment using chlorination.

The H_2S level in the raw water supply requires additional treatment beyond the tray aeration and chlorination typical at many of JEA's water treatment plants. Therefore, JEA initiated a desktop evaluation and assessment of treatment alternatives for reduction of H_2S in the groundwater supply. Several treatment processes were contemplated during the desktop assessment as follows:

- Packed tower aeration with odor control chemical scrubbers
- In-line ozone oxidation followed by cascade aeration
- In-line chlorine dioxide oxidation followed by cascade aeration
- Bulk hypochlorite oxidation followed by media oxidizing filtration
- Anion exchange

With sulfide levels ranging from 1.4 to 2.6 mg/L, packed tower aeration (forced draft aeration) and ozonation followed by cascade aeration were deemed the two most viable treatment technologies and considered for further study. Table 1 outlines the basic raw water quality data used for further design efforts.

Packed Tower Aeration Versus Ozone Oxidation

Based on the outcome of the treatment alternatives assessment, JEA authorized the design-build team to provide preliminary design and pricing for each of the packed tower aeration and ozone oxidation alternatives. Thirty percent design-level drawings and the associated report were developed for each alternative so that construction costs could be developed for each. In addition, operating costs were also considered in order to develop a life cycle cost comparison. Elements of each alternative are outlined as follows:

Packed Tower Aeration Preliminary Design Elements

- Packed tower aerators
- Carbon dioxide feed system
- Chemical booster pumps
- Sodium hypochlorite system
- Chemical storage and feed building
- Biotrickling filter for odor control
- Transfer pumping station
- Low pH blow-down pump station
- Piping
- Instrumentation and controls
- Major electrical

Ozone Oxidation Preliminary Design Elements

- Liquid oxygen (LOX) storage and vaporization
- Gaseous oxygen (GOX) pressure regulation and filtration
- Supplemental air system
- Ozone generator and associated power supply unit
- Closed-loop cooling water system
- Open-loop cooling water system
- Ozone dissolution system including injectors, degas separators, and injection spool
- Ozone contactor
- Ozone off-gas destruct units
- Ozone building
- Cascade tray aeration
- Piping
- Instrumentation and controls
- Major electrical

Comparative project cost for each alternative is as follows:

- Project costs with packed tower aeration system = $13.9 million
- Project costs with two 2000-lb ozone generators = $12.9 million

Through an evaluation of life cycle costs, it was determined that the cost for maintaining the packed tower system would be greater than operation of the ozone system. Therefore, ozone generation was selected as the best option for reduction of H_2S from the groundwater.

Ozone Oxidation

Ozone is an unstable compound that is not readily stored, thus it has to be produced on site. The WTP is equipped with an ozone generation system that requires two main ingredients for ozone production: oxygen (O_2) and electricity. The O_2 is stored in its liquid state, or LOX. The LOX will be delivered by truck and stored on site in two 6,000-gal tanks. Two tanks have been installed for redundancy. The tanks operate by keeping the LOX under the necessary temperature and pressure needed to maintain the O_2 in its liquid state. In order to keep O_2 in a liquid state, it needs to be kept below its boiling point of -183°C (-297°F) at one atmosphere, which means that the operational ranges of the tank require extremely low temperatures relative to the surroundings.

Continued on page 42

Continued from page 40

As LOX leaves the storage tank, it enters the vaporizer in order to be converted to GOX. The ozone system at the WTP has two vaporizers on site, one for each tank. The vaporizers consist of coils of 316 stainless steel tubing and aluminum heat fins to promote heat exchange from the atmosphere to the super cold liquid. Again, due to the extremely low boiling point of O_2, heat transfer from the surrounding atmosphere, even in the winter months, is sufficient to convert the LOX to GOX. As the LOX coverts to GOX, the moisture content must be monitored and kept below a certain level for proper operation of the ozone generator.

Figure 2 summarizes the basic operation of the ozone generation system. The ozone generator needs GOX, supplemental air, and electricity to drive the reaction that creates ozone. All of the piping, fittings, and components associated with the ozone system are 316 stainless steel. Stainless steel is the material of choice over the more common ductile iron or steel application because oxygen aggressively attacks hydrocarbons and these materials would rapidly corrode. When the ozone leaves the system, it can then go to either the injection system or through the destruct units to be discharged as oxygen to the atmosphere. One open-loop and one closed-loop cooling water system is provided for heat rejection in order to keep the ozone generation equipment cool during operation.

The reaction inside the ozone generator is defined as the partition of the diatomic O_2 molecule into single oxygen atoms via supplied energy. This reaction is commonly compared to lightning strikes, which also form ozone. The high voltage strike splits oxygen molecules and allows the free oxygen atoms to partner with adjacent O_2 molecules and form O_3. With the ozone formed, it is ready for the next step in the process.

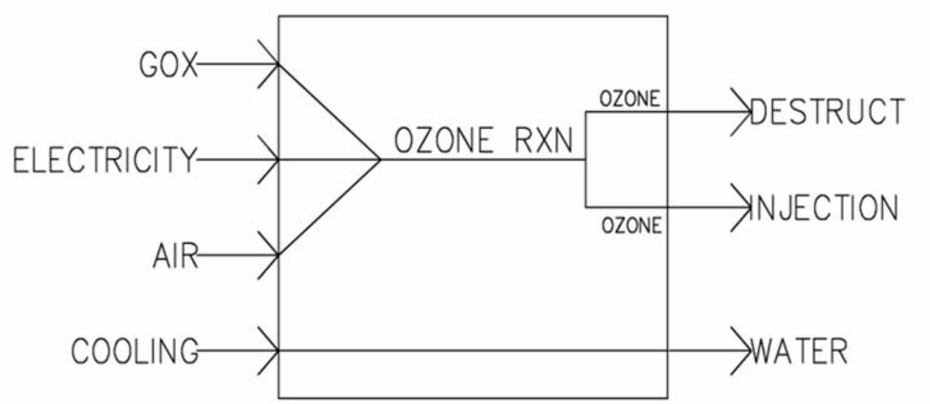

Figure 2. Ozone Generation System

Table 2. Risk Allocation Matrix

		Design-Bid-Build (DBB)	Progressive Design-Build (DB)
Design and Construction	Design Build Cost	JEA	Haskell/B&V Team
	Design Defects	JEA	Haskell/B&V Team
	Errors and/or Omissions	JEA	Haskell/B&V Team
	Constructability	JEA	Haskell/B&V Team
	Schedule/Completion	JEA	Haskell/B&V Team
	Construction Warranties	JEA	Haskell/B&V Team
	Hazardous Materials	JEA	JEA
	Unidentified Utilities	JEA	Haskell/B&V Team
	Changing Soil Conditions	JEA	Haskell/B&V Team
Asset Management	System Performance	JEA	Haskell/B&V Team
	Life Cycle Costs	JEA	JEA
	Operations and Maintenance	JEA	JEA
Legal	Third-Party Litigation	JEA	JEA

Ozone Transfer

After the ozone is created in the generator, it is injected into the raw water using sidestream injection, in which the ozone gas is mixed into an aqueous solution in a device called a Mazzei® Injector. There are two pumps with a rated capacity of 1,460 gpm each that pull water from the raw water supply line. The ozone is injected into one of two pipes where this water is then sent to the sidestream injection point at the beginning of the ozone contactor and is mixed as it passes the static mixer. As the ozone is injected into the water, it oxidizes the H_2S, removing the foul taste and odor. The ozone contactor is a special section of 36-in. 316 stainless steel pipe, with length of 300 ft, routed both aboveground and the majority underground. Along the length of the contactor is an off-gas collection point to capture any excess ozone and oxygen that has not mixed with the water. This off-gas is routed to a collection chamber where the ozone is then routed to the ozone destruct unit. The contactor pipe is ozone-resistant stainless steel that will not corrode should an ozone residual be retained in the pipe. The constructed length of pipe provides approximately 1.5 min of contact time at design flow, which will allow the ozone residual to decay within the contactor.

Improved Ozone Transfer Efficiency Using Sidestream Injection

Historically, in water treatment facilities, ozone has been injected into the process stream as a gas through wafer-style diffusers that are located in an ozone contactor basin. Often times, the contactor is a concrete structure, where the structure and diffusers require routine maintenance. The ozone gas "bubbles" through the water and is transferred to the liquid phase where it oxidizes the H_2S. The ozone contactor basin is considered less efficient than sidestream injection. With sidestream injection, the more efficient transfer of ozone reduces operating costs and also requires less space, both deciding factors for the WTP ozone system.

Cascade Tray Aeration: The Final Treatment Step

One unique element of the WTP ozone system design is the concept of only partial oxidation of the H_2S. The established goal for target sulfide concentration of 0.3 mg/L was based on the ozone treatment reducing the H_2S from 2.6 mg/L to 0.6 mg/l. The cascade tray aeration system would then further reduce the concentration from 0.6 mg/L to 0.3 mg/L, the level acceptable for treatment using chlorination.

The cascade tray aerator is located on top of the OSR dome. The aerator design is based on a maximum flow rate of 24 mgd. Flow is routed through a center pipe to the top of the aerator and cascades down over seven trays to the top of the dome and will then drop into the tank through circular openings in the dome. The aerator is constructed of fiberglass and stainless steel hardware. The outside of the aerator is enclosed with fiberglass screen and the top is covered by a fiberglass reinforced plastic roof. The aerator is approximately 26 ft in diameter.

The aerator's H_2S removal efficiency is affected by the number of trays provided. A typical cascade aerator design includes four trays. As stated in the paper, "Desk Top Evaluation of Hydrogen Sulfide Removal Technologies for JEA's Main Street Water Treatment Plant," by Steven J. Daranceau, the efficiency can be increased to as much as 50 percent by providing a seven-tray design. Added benefit of additional trays beyond seven is limited and, therefore, not considered. The aerator height will be approximately 13 ft above the center of the reservoir dome. The H_2S removed from the water at the aerator will be released directly to atmosphere. No provisions are provided for capturing the H_2S removed since the anticipated concentration of H_2S fugitive gas emissions will be below detectable limits.

Project Delivery: Progressive Design-Build

The JEA decided to utilize the alternative delivery method of progressive design-build on the WTP project after developing a risk allocation matrix, which identified the project as the key to success for the $80 million TWMP program. As the primary pumping station for moving water from the North Grid to the South Grid, the WTP work had to be completed and operating prior to the commissioning of the TWMP project.

The JEA recognized that they could perform a no-cost evaluation of alternative H_2S removal technologies, get alternative cost estimating, use innovation to meet the budget, design the facility, and perform the construction, all under one progressive design-build contract. For JEA, progressive design-build provided the opportunity to look at multiple options, explore alternatives, and meet its schedule and budget.

In addition, progressive design-build allowed JEA to shift significant risk to the design-builder. The risk allocation matrix shown in Table 2 identifies potential risks and compared ownership of risk under traditional design-bid-build and progressive design-build.

Based on the risk analysis, JEA concluded it was more likely that the progressive design-build would reduce its risk than design-bid-build. In addition, JEA's objectives included the following elements:

- A single point of accountability
- Reduced and managed risk allocation
- Early contractor involvement
- Value engineering
- Reliable constructability reviews
- A team committed to cost and schedule controls

To meet these objectives, JEA choose progressive design-build as the delivery method for the WTP/OSR project.