BY JERRY EDWARDS
AND JAMES MAHER

NEW UNDERSTANDING OF WATER QUALITY DETERIORATION IN DISTRIBUTION SYSTEMS INDICATES THAT MORE CONSIDERATION SHOULD BE GIVEN TO THE APPROPRIATE SITING OF STORAGE FACILITIES.

Water quality considerations for distribution system storage facilities

Aging water in distribution system storage facilities can have a detrimental effect on the quality of water delivered to customers. Excessive water age may lead to increased disinfection by-product (DBP) formation and loss of chlorine residual. Utilities that use chloramination for final disinfection in order to minimize DBP formation often experience nitrification problems in storage facilities as a result of extended water age.

This article reviews the types of typical distribution system storage facilities, summarizes the factors that influence the selection of storage facilities, and recounts recent cases of distribution water quality issues traced to storage facilities. In an investigation of water quality problems at a Nebraska distribution system, the authors conducted extended period simulation (EPS) of water age and source trace analyses to evaluate how operation, type, and location of storage facilities affected distribution system water quality in a sample pressure zone. Results of the EPS analyses demonstrated the relative effect that the type and location of a storage facility can have on water quality in the distribution system.

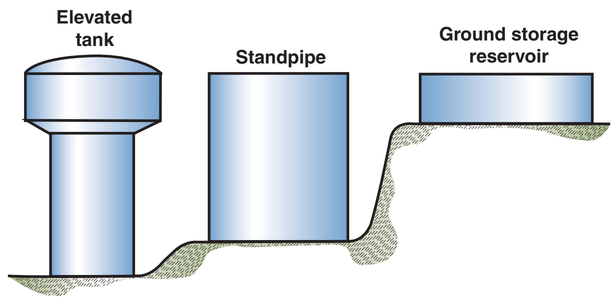
STORAGE FACILITIES VARY BY TYPE AND LOCATION

Distribution system storage can be provided by several different types of facilities. Hydraulically, there are two significant categories of storage facilities: pumped storage and floating storage. At pumped storage facilities, pumping must be provided to supply adequate pressure to the system or pressure zone. At floating storage facilities, the free surface of the water in the facility establishes the hydraulic gradient in the system or pressure zone. Floating storage can be provided by elevated tanks, standpipes, or ground-level storage. The term standpipe refers to a cylindrical tank whose height is greater that its diameter. Ground-level storage can be above ground, partially buried, or buried. This article focuses on floating storage facilities, whether elevated tanks, standpipes, or ground storage. Figure 1 depicts the most common types of floating storage.

Many factors influence selection of the type of storage facility for a particular situation. The variation of terrain within a system, cost considerations, a need for emergency storage, and aesthetics all play a role in storage tank selection. Historically, appearance has sometimes influenced the selection of standpipes over elevated tanks. A 1965 engineering report for a small utility in Massachusetts stated that a standpipe or elevated tank would show on the horizon and that its appearance should be considered in the selection process (Weston & Sampson Consulting Engineers, 1965). Because an elevated tank had an "industrial look," the report recommended construction of a standpipe, even though the cost of the standpipe was expected to be about 10% more than the cost of an elevated tank.

Where ground elevations allow, many utilities prefer to locate storage facilities on higher ground and use ground-level storage tanks or standpipes. This is often cost-effective and minimizes the obtrusiveness of a taller storage facility. When new water distribution storage facilities are constructed, it has long been common practice to use ground storage facilities or standpipes located on high ground in order to minimize total construction costs. A US Army Corps of Engineers technical instruction on water distribution states that "water storage can be most economically provided by constructing ground storage reservoirs on high ground" and "the most economical alternative for meeting the water storage requirements will be selected in all cases" (DOD, 2005). Recent information compiled by the Southeastern Wisconsin Regional Planning Commission stated, "In some cases, ground-level or underground storage systems can be sited at higher elevations, allowing for gravity service to all or portions of a service area or pressure zone" (SEWRPC, 2006). A technical brief on storage facilities issued by the National Drinking Water Clearinghouse included this note: "In hilly areas, however, it may be more advantageous to select the highest point for construction of an elevated tank which may lie at one end of the area instead of the center" (Bhardwaj, 2001).

FIGURE 1 Types of floating distribution system storage

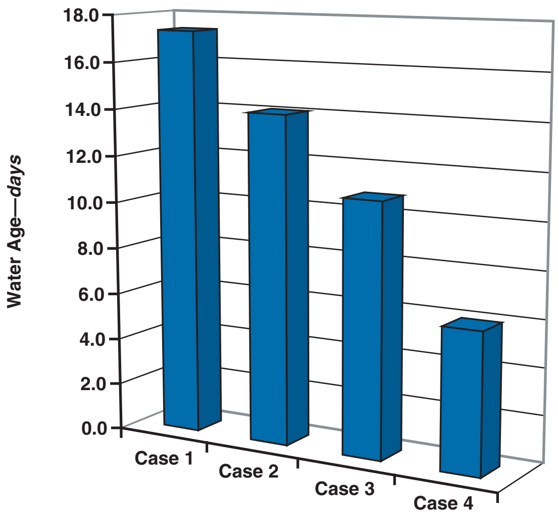


WATER QUALITY ISSUES HAVE BEEN REPORTED IN STORAGE FACILITIES

A recent Awwa Research Foundation (AwwaRF) report, "Managing Distribution Retention Time to Improve Water Quality," described several cases of water quality concerns related to storage facilities (Brandt et al, 2005). In one instance, the South Central Connecticut Regional Water Authority in New Haven was experiencing high DBP concentrations at locations in the distribution system, triggering concerns that the levels might exceed the maximum contaminant level (MCL) established under the Stage 2 Disinfectants/Disinfection By-products Rule (Stage 2 D/DBPR). The average demand in the system was ~ 6 mgd, and treated water was supplied by one water treatment plant. A single elevated tank with a volume of 4.0 mil gal provided distribution system storage and was located on a long pipeline at the periphery of the system. Computer analyses showed that the water provided by the treatment plant tended to bypass the tank, resulting in high water ages in the tank and surrounding area. Further analyses indicated that revalving the system to reduce all water ages to an acceptable level was not feasible. In order to maintain DBP levels below the future MCLs imposed by the Stage 2 D/DBPR, several improvements were recommended. These treatment upgrades included ozone disinfection and installation of activated carbon filtration.

In another case cited in the AwwaRF report, the Champlain Water District, serving about 70,000 customers in northwestern Vermont, experienced low chlorine residuals and high DBP concentrations in a floating ground storage tank and the surrounding area (Brandt et al,

FIGURE 2 Comparison of water age for case study analyses



Case 1 = standpipe outside demand area, 15-ft fluctuation; case 2 = standpipe outside demand area, 20-ft fluctuation; case 3 = elevated tank outside demand area, 15-ft fluctuation; case 4 = elevated tank within demand area, 15-ft fluctuation

2005). The tank had a volume of ~ 2.2 mil gal and was located on a hill outside the demand area at the end of a nearly 1-mi-long transmission main. Extensive computation fluid dynamics modeling was performed to evaluate tank modifications to increase mixing in the tank. The recommended modifications included separate inlet and outlet piping with an arrangement to maximize mixing. In addition, final disinfection at the treatment plant was switched from chlorination to chloramination in order to reduce DBP formation in the distribution system. Nevertheless, concerns remained about the aging water in the tank, which resulted from the limited turnover because of the tank's location. Further investigation indicated that an additional pump station might be required in the future to increase demand on the tank should nitrification occur.

Case study demonstrated benefits of hydraulic modeling. Water quality analyses were conducted by the authors to evaluate water quality problems in a pressure zone in the Lincoln (Neb.) Water System (LWS). Low chlorine residuals had been experienced at the far end of the pressure zone near a standpipe providing storage to the zone. At the time of the initial analyses, the pressure zone had an average day demand of ~ 4 mgd, and storage was provided by a 3-mil-gal standpipe with a height of 95 ft and a diameter of 75 ft. The standpipe was on the opposite end of the pressure zone from the primary pumping station supplying the zone and was at the end of a transmission line, ~ 0.5 mi past the last distribution main in the system.

Detailed hydraulic modeling determined that the water ages in the area were some of the highest in the entire distribution system. The high water ages were determined to be primarily attributable to the standpipe being situated beyond the location of the demands in the system. This resulted in a "sloshing" effect of water being repeatedly cycled into and out of the reservoir during normal fill-and-draw cycles. Water that drained from the standpipe during a draw cycle was not completely withdrawn from the distribution piping and was then pushed back into the reservoir during a fill cycle, which resulted in aging water in the standpipe and in the system. Water quality deterioration was exacerbated by the presence of unlined cast-iron pipes that were depleting the chlorine residual. LWS has since initiated a program to remove or replace much of the cast-iron pipe. Water quality will continue to be monitored in the area with potential for additional capital improvements to be considered if water quality problems continue.

HYDRAULIC MODELING CAN HELP EVALUATE WATER QUALITY PARAMETERS

EPS analyses were conducted for the LWS pressure zone. In order to quantify how water quality is affected by various tank operational parameters, as well as the type and location of various storage facilities, the authors conducted water age and source trace analyses using a detailed model of the pressure zone. Four unique cases were analyzed. These analy-

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ses were conducted specifically for this research and not necessarily to identify improvements for the distribution system.

Model details and parameters described. The model contained all pipes 4 in. and larger, storage facilities, and pump station pump curves for the actual pressure zone. Detailed demand allocation was performed using itemized billing records. Source trace analyses from the primary pumping station and water age analyses were performed using a duration of 1,200 hours (50 days). This long duration was selected to ensure that equilibrium conditions were achieved in the model. A typical average day diurnal demand curve was applied to allocated average day demands and repeated for each 24-hour period. All cases were analyzed with 100% of the water to the pressure zone supplied by the primary pumping station. Complete mixing was assumed to occur within the tank.

Different scenarios facilitated comparison of various factors. The four cases were analyzed to evaluate the water quality parameters of water age and storage facility turnover in the sample pressure zone model. Initial analyses verified the efficacy of increasing the operational water level fluctuations in the standpipe. In case 1, EPS water age and source trace analyses were performed using operational controls at the primary pumping station such that water levels in the standpipe fluctuated over a range of 15 ft (water levels of 75–90 ft). Under these conditions, the tank was cycling approximately two times per day.

Case 2 was performed with operational controls at the primary pumping station that allowed water levels in the standpipe to fluctuate 20 ft (water levels of 70–90 ft). Under the revised operational controls, the tank was cycling about once per day. The analyses indicated that increasing the operational fluctuation from 15 ft to 20 ft reduced the water age by almost 20%, from approximately 415 hours (17 days) to approximately 340 hours (14 days).

Source trace results showed that increasing the operational fluctuation improved the rate of turnover, or influx of fresh water, in the tank. The turnovers calculated by the model were much longer than those that would be determined by a simple calculation of tank turnover on the basis of average daily number of fill-and-draw cycles and the level of operational fluctuation. For example, in case 1, the tank cycled approximately twice per day over a 15-ft range. A simple calculation might indicate that the tank would have all its water replaced every 2.5 days (90 ft high/15 ft per cycle/two cycles per day = 2.5 days). However, model results for case 1 showed that after 2.5 days, only about 10% of the water in the tank had been replaced with fresh water from the pumping station supply source.

In the case 3 analysis, the authors set out to determine whether water age in the distribution system would be lower if an elevated tank had been constructed at the site instead of a standpipe. The analysis assumed that the elevated tank would have the same diameter as the standpipe, with a total depth of 37.5 ft. At 37.5 ft of depth and the same diameter, the elevated tank would have a volume of 1.25 mil gal. The analysis assumed an operational fluctuation of 15 ft for the elevated tank and was compared with the case 1 analysis described previously. Comparison of the analyses indicated that

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FIGURE 3 Movement of water in system for a storage facility outside the demand area

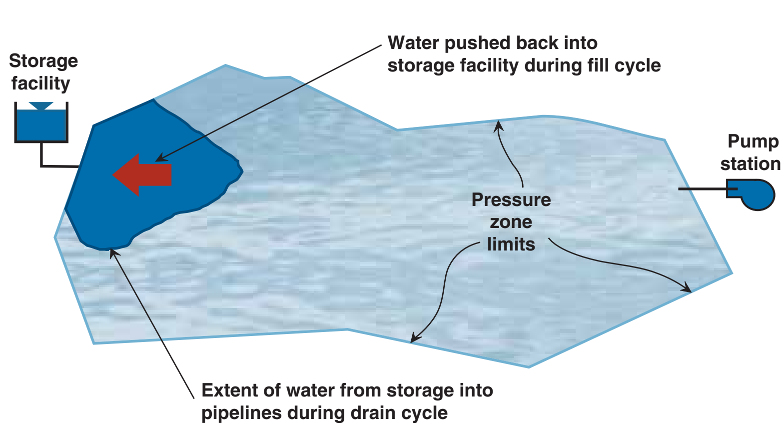
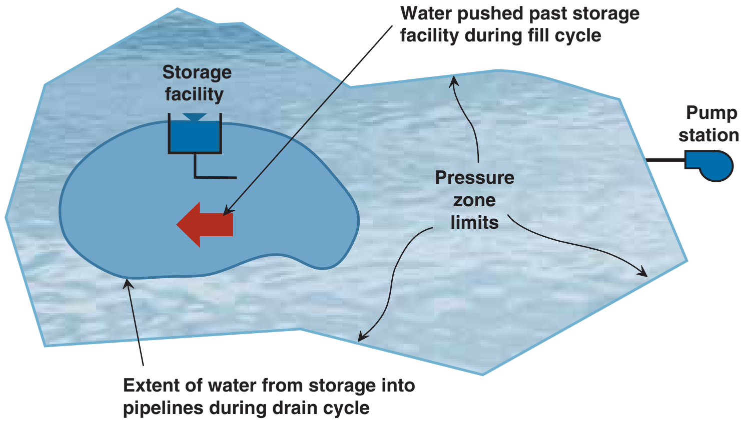


FIGURE 4 Movement of water in system for a storage facility within the demand area



replacing the standpipe with an elevated tank reduced water age by almost 40%, from approximately 415 hours (17 days) to approximately 260 hours (11 days).

The case 4 analysis was conducted to determine whether water age would improve significantly if an elevated tank had been constructed at a location within the demand area of the pressure zone. The analysis assumed that the elevated tank would have the same characteristics as the elevated tank in case 3, with a depth of 37.5 ft and a volume of 1.25 mil gal. The analysis assumed an operational fluctuation of 15 ft for the elevated tank and was compared with the case 3 elevated tank analysis described previously. Comparison of the analyses indicated that relocating the elevated tank to a site within the demand area reduced water age by almost 45%, compared with an elevated tank located outside the demand area. Water ages were reduced from about 260 hours (11 days) to approximately 144 hours (6 days). A comparison of the elevated tank within the demand area to a standpipe outside the demand area showed a reduction in water age of 65%, from 17 days to 6 days. Figure 2 compares water ages for each of the four cases.

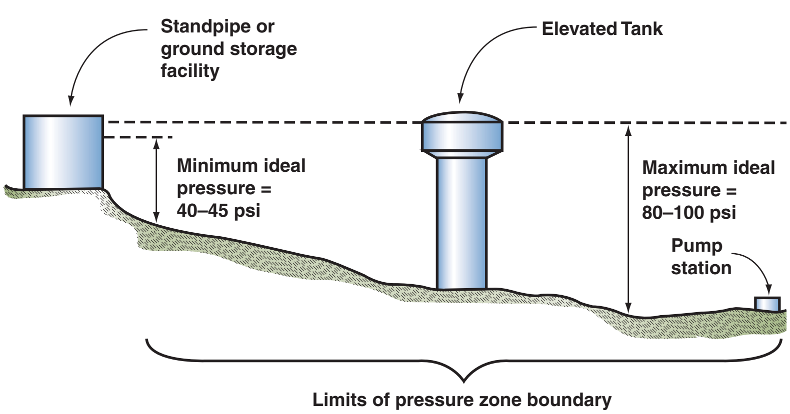
Analyses looked at water movement in the distribution system. The source trace analyses were reviewed to investigate how water moved through the distribution system over time. As stated previously, the source trace analyses showed that locating the storage facility beyond the demand area had led to a sloshing effect of water being repeatedly cycled into and out of the reservoir during normal fill-and-draw cycles (Figure 3). Source trace analyses for the case 4 condition indicated that when the storage facility was located within the demand area, the water that drained from the tank was pushed past the tank during the fill cycle, resulting in significantly reduced water ages in the distribution system (Figure 4).

STORAGE DECISIONS SHOULD CONSIDER OVERLOOKED FACTORS

Much of the available literature on maintaining water quality in distribution system storage facilities has focused on two aspects—mixing within the tank and operational considerations to maximize turnover—with only limited discussion of a third factor (and one that should be considered of significant importance in new construction), i.e., the location of the facility relative to the system it serves. The two-pronged focus on mixing within the tank and maximizing turnover is understandable, given that the majority of evaluations have been conducted for existing systems that are experiencing problems and it is usually not economically feasible to relocate a storage facility for the purpose of increasing water quality. However, when new construction is in the offing, utilities should give significant consideration to the location of storage facility relative to water quality in the distribution system.

Decisions about storage should factor in considerations beyond initial cost. Compared with an elevated tank, a

FIGURE 5 Storage facilities and pressure requirements



standpipe or ground storage reservoir generally can be constructed more economically, which is one reason that standpipes and ground storage reservoirs are often selected in lieu of elevated tanks. However, standpipes and ground storage reservoirs may be susceptible to high water ages. Pressure is inadequate in the distribution system directly adjacent to floating ground storage facilities but the facilities are situated on high ground, which places them outside the demand area as shown in Figure 5. Similarly, in order to obtain the ground height required, standpipes often must be located beyond the demand area in a pressure zone. When depleted by 15 ft, a standpipe with a height of 90 ft provides a pressure of only ~ 32 psi at ground level; typical desired minimum service pressure is 40 to 45 psi. Therefore, a standpipe usually does not provide adequate service in the immediate area around the tank. In a recent discussion with a manufacturer of steel storage facilities, the authors learned that construction of standpipes has in fact declined significantly in recent years because of water quality concerns (Bach, 2007).

When siting a new storage facility, planners must understand how water moves through a distribution system. Poor site location can have a seriously detrimental effect on distribution system water quality. The outcome may be high water age and corresponding low chlorine residuals as well as possible positive coliform results or high DBP formation leading to levels exceeding the MCL of the Stage 2 D/DBPR. In light of potential water quality problems, water utilities should reconsider their preference for the least-cost construction alternative as a primary factor for determining storage type and location.

EPS source trace analyses can be used to provide a clear understanding of the movement of water through a distribution system. Many situations will likely be more complex than the sample pressure zone presented here, and EPS modeling can be an effective tool in identifying how storage facilities affect water quality in the distribution system.

Water quality problems may persist, even with good mixing characteristics in a storage tank, and improvements required to reduce high water ages for storage facilities located outside the demand area can be expensive. Although modifications to the tank to facilitate mixing may improve water quality, the relative effect of tank location may be of much greater significance.

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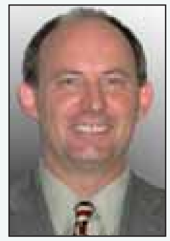
ABOUT THE AUTHORS



Jerry Edwards (to whom correspondence should be addressed) is director of infrastructure planning at Black & Veatch Corp., 8400 Ward Pkwy., Kansas City, MO 64114; e-mail edwardsja@bv.com. He has more than 22 years of engineering consulting experience in the water industry and specializes in planning of water distribution systems. He holds a BS degree in civil engineering from the University of Missouri at Rolla and an MS degree in civil engineering from the University of Kansas at Lawrence. James Maher is a planning engineer at Black & Veatch in Kansas City.

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