AMC ENGINEERS

CIVE 4375-02 Water & Wastewater Treatment

Preliminary Design Report

Group 1

Matt Medeiros, Christian Paim, Amanda Siciliano

23 March 2020

Department of Civil Engineering
Wentworth Institute of Technology
Boston, MA 02115

Preliminary Design Report

AMC ENGINEERS

Date: March 23, 2020
To: Dr. Gautham P. Das, Elder Endowed Professor
From: Matthew Medeiros, Christian Paim, Amanda Siciliano
Subject: Preliminary Design Report for Big Bluff Water Treatment Plant

Dear Dr. Das,

Attached please find AMC Engineers preliminary design for the proposed water treatment plant throughout the town of Big Bluff.

This design is based on the information provided through the project contract documents distributed to all consulting engineering companies. Please note that any revisions to the existing conditions in Big Bluff could result in a change in the proposed design.

This design assumes that all involved parties will work together to develop a sustainable and constructable water treatment plant. Please note that all engineering assumptions and justifications are clearly noted in the proposal.

Thank you for providing AMC Engineers with this opportunity. The company looks forward to hearing from your organization.

Sincerely,

AMC Engineers

Matthew Medeiros
Christian Paim
Amanda Siciliano

Executive Summary

The town of Big Bluff is bidding a development of their water treatment plant. The community needs advising on a modern treatment plant that will meet the developing area. Over the last 50 years, the town has been developing to include an industrial manufacturing facility and large tourist population. Previously, the only treatments used for drinking water have been chlorination and filtration. These methods, which were being used to treat local river water, are no longer sufficient to meet the developing needs of the growing population. Geological reports indicate that underlying bedrock causes water to have high concentrations of products such as calcium, manganese, and iron. Through a variety of water treatment techniques, AMC Engineers will provide the plans for a feasible and modern treatment plant. The methods involved in completing this project requires knowledge of population growth, water demands, flow calculations, treatment unit operations, and site layout. AMC Engineers determined that the town of Big Bluff requires a water treatment plant that uses shallow wells. This shallow well treatment process includes screening, lime softening, flocculator clarifiers (excess lime, iron, and manganese removal), mixing, flocculation, sedimentation, fluoridation, dual-media sand filtering, and chlorination. These principal findings come as a time and cost effective solution in developing a water treatment plant for the community.

Table of Contents

Population Projections

Population Growth

Reports indicate that the current population within Big Bluff is 35,000 people year round. However, this population swells to approximately 50,000 people during the busy summer and winter seasons due to tourism. As a result, it is important to evaluate the cyclic population growth patterns over the span of the upcoming thirty years, with a projected 3% annual increase. In order to consider the changes to the town, a "worst-case" scenario evaluation was considered. To evaluate these changes, the following formula was used:

$$P = P_0 e^{rt}$$

Using the 3% annual projection population growth over the 30 year spans, both the year round and seasonal populations were projected. Using the previous formula, calculations indicate that the year round population of 35,000 people will grow to 86,090 while the seasonal population of 50,000 people will grow to 122,980. These calculations are projected to be the population amount by 2050.

Design Flow Calculations

Water Demand

To ensure an adequate and modern water treatment plant, it was important to consider the growing water demands throughout this bustling medium-sized community. The different residential, commercial, and industrial facilities located throughout Big Bluff were evaluated for peak water demand performance. These values were recorded based on the anticipated population growth that would occur at the end of the 30 year life span. By estimating the daily water demand for the different establishments for the year 2050, it allows the system to prepare for the maximum daily usage for the varying units.

Because the town of Big Bluff has a variety of different establishments, multiple sources were used to evaluate total water demands, as displayed through *Table 1.0 Water Demands for Big Bluff Establishments*. This table assesses the different establishments and includes the quantity and description of total size in order to produce a daily and total water demand. Note that water demands are provided in gallons per desired unit, while total water demands are provided in gallons per day (GPD).

Table 1.0 Water Demands for Big Bluff Establishments

Establishment	***Quantity***	***Description of Total Size***	***Unit Description***	***Water Demand (per day)***	***Total Water Demand (GPD)***
Residential	30,000 homes	Varies (¼ acre - 2 acre plots)		260 $\frac{gal}{house}$	7,800,000
Swimming Pools	2	80,000 people		25.5 $\frac{gal}{person}$	2,040,000
Textile Plant	1	2 floors (6,000 ft^2)		7,180 $\frac{gal}{plant}$	7,180
Shopping Malls	3	3 acres (130,680 ft^2)		0.16 $\frac{gal}{ft^2}$	20,910
Grocery Stores	2	2 acres (87,120 ft^2)		0.16 $\frac{gal}{ft^2}$	13,940
Gasoline Stations	5	22 pumps		65 $\frac{gal}{pump}$	1,430
Dry Cleaners & Laundromats	3	35 washing machines		40 $\frac{gal}{machine}$	1,400
Barber Shops	2	7 chairs		55 $\frac{gal}{chair}$	385
Beauty Salons	2	12 chairs		270 $\frac{gal}{chair}$	3,240
Restaurants	7	850 patrons		24 $\frac{gal}{patron}$	20,400
Total					**9,908,885**

One of the largest water demands comes from the residential area. While it is anticipated that, based on current population rates, approximately 13,000 homes exist in Big Bluff, population growth projections estimate that nearly 32,000 homes will exist after a 30 year period with an annual 3% growth. As a result, water demand calculations were projected for 30,000 homes to anticipate seasonal influx, resulting in a total residential water demand of 9,908,885 GPD (Emrath 2017). This same population projection of 80,0000 people was used to calculate water demands for the 2 swimming pools throughout the town, which totaled 2,040,000 GPD (Maglionico, Stojkov 2015). The textile plant totals a water demand of 7,180 GPD after averaging the demands of 10,000 GPD for work days and 100 GPD for weekends and holidays. The shopping malls and grocery stores used similar water demands based on square footage, that totaled 20,910 GPD and 13,940 GPD, respectively (Action MFG 2019). The 5 gas stations, with a total of 22 pumps, required 1,430 GPD (Broward County Florida 2012). Some of the different businesses in Big Bluff, such as the dry cleaners & laundromats, barber shops, and beauty salons used water demand values of 1,400 GPD, 385 GPD, and 3,240 GPD, respectively (Homes Water Works 2019; Action MFG 2019). The 7 local restaurants, seating approximately 850 patrons, used 20,400 GPD (Flusberg 2016). Many of these water demand values for the various establishments were based on the building square footages, pumps, chairs, or patrons. It is projected that, despite the increased seasonal populations and anticipated projection growths, the 30 year life span of this water treatment plant will have a total water demand of 9,908,885 GPD.

Selection of Treatment Unit Operations

Some of the different treatment unit operations include screening, presedimentation, and chemical addition (Viessman and Hammer 2005). Ultimately, it was decided that following a shallow well treatment system would best suit the needs of Big Bluff. This shallow well unit operation includes lime addition, flocculator clarifiers, mixing, flocculation, sedimentation, iron and manganese removal, fluosilicic acid fluoridation, dual-media sand filtering, and chlorination.

Justification of Treatment Unit Operations

Fine Screen

Fine screens are used for this water treatment plant to remove suspended and floating debris located within the water. In particular, these screens are designed to remove suspended and settleable solids in pretreated water. It is likely that these contaminants come from natural debris. These are the best option for removal of early contaminants because the screens provide an opportunity to remove any materials, at an early stage, that can damage pumps downstream.

Lime

Lime is used for softening reactions. Since the aquifer is located in an area that consists of ancient marine sedimentary rock in addition to significant igneous rock dike intrusions, there are high concentrations of calcium, magnesium, manganese and iron mixing into the water supply. The calcium and magnesium ions are what cause water hardness. Lime additions remove the hardness-causing precipitates from the solution.

Flocculator-clarifiers

Flocculation agitates treated water to turn small suspended particles to larger, heavier particles that are settled out by gravity. This is completed through the steps of mixing, flocculation, and sedimentation. Mixing, flocculation, and sedimentation are designed to remove the chemical reactors in water treatment.

Iron and Manganese

Iron and manganese stain plumbing fixtures, discolor water, cause foul tastes, and odor. Potassium permanganate is used in the oxidation of iron and manganese. Potassium permanganate is faster than chlorine for the oxidation of manganese and the rate of reaction is somewhat independent within a pH range of 5-9.

Fluosilicic acid

Fluosilicic acid is used for the fluoridation of the water. Fluoride in drinking water, at the right levels, can benefit people by reducing the prevalence of osteoporosis and hardening of the arteries. Fluoride is added to public water supplies at optimum levels as a public health measure.

Dual-media coal-sand filter

The dual-media filter is for the removal of unsettled hardness precipitate and oxidized iron and manganese floc. The dual-media coal-sand filter removes colloidal impurities of the earlier water treatment processes.

Disinfection - Chlorine

Chlorine is one of the most common chemical disinfectants for water treatment. Chlorine is less expensive than other disinfection options. It is used in this treatment process as the last step to establish a free chlorine residual throughout the distribution system.

Sizing of Unit Operation Reactors

Fine Screen

A fine screen with 5 mm spacing has been selected to meet the needs of Big Bluff. This screen will serve as the first step within the water treatment process.

Lime

To understand the excess-lime treatment, it is important to understand the different components, hardnesses, chemical reactions, and equivalency conversions. The components of the lime treatment are listed in Table 1.1, with following equations displaying the total hardness, carbonate hardness, and noncarbonate hardness values. Next, Table 1.2 displays the Milliequivalent Bar Chart of Lime Treatment, a crucial visual for understanding the lime treatment compound results that are displayed in Table 1.3.

Table 1.1 Components of Lime Treatment

		Component	**Concentration**	**Molecular Weight**	**Eq/molecule**	**Equivalent Weight**	**meq/L**	**mg/L as CaCO3**
$\sum =$	6.03	Ca^{2+}	78	40	2	20	3.90	195.00
		Mg^{2+}	26	24.4	2	12.2	2.13	106.56
$\sum =$	6.03	HCO_3^-	151	100	2	50	3.02	151.00
		SO_4^{2-}	133	96	2	48	2.77	138.54
		Cl^-	8.5	35.5	1	35.5	0.24	11.97
		CO_2	9.7	44	2	22	0.44	22.05

$$Total\ Hardness = Ca + Mg = 301.56\ mg/L\ as\ CaCO_3$$
$$Carbonate\ Hardness = HCO_3 = 151.00\ mg/L\ as\ CaCO_3$$
$$Noncarbonate\ Hardness = Total - Carbonate = \ = 150.56\ mg/L\ as\ CaCO_3$$

Table 1.2 Milliequivalent Bar Chart of Lime Treatment

0		3.9	6.03
CO2	Ca		Mg
	HCO3	SO4	Cl
0.44	3.02	5.79	6.03

Table 1.3 Calculated Compounds within Lime Treatment

Compound	***Amount (meq/L)***
CO_2	*0.44*
$Ca\ (HCO_3)$	*3.02*
$Ca\ (SO_4)$	*0.88*
$Mg\ (SO_4)$	*1.89*

Using the previous information regarding calculated compounds and components, the total required lime can be calculated based on the following chemical reactions:

$$CO_2 + Ca(OH)_2 \rightarrow Ca\,CO_3 + H_2O$$
[0.44] [0.44]

$$Ca\,(HCO_3) + Ca(OH)_2 \rightarrow Ca\,CO_3 + H_2O$$
[3.02] [3.02]

$$Mg\,(SO_4) + Ca(OH)_2 \rightarrow Mg(OH)_2 + Ca\,SO_4$$
[1.89] [1.89]

$$Total\ Lime\ Required = 0.44 + 3.02 + 1.89 = 5.35\ Meq/L$$

To determine the lime equivalent weight and lime required, the following equations are used:

$$Lime\ Equivalent\ Weight = \frac{Molecular\ Weight}{Charge} = \frac{40 + (16 * 2) + (1 * 2)}{2} = 37\ mg/Meq$$

$$Required\ Ca(OH)_2 = (\ 5.35\ Meq/L\ *\ 37\ mg/Meq\ ) + (1.25\ Meq/L\ *\ 37\ mg/Meq) = 244.2\ mg/L$$

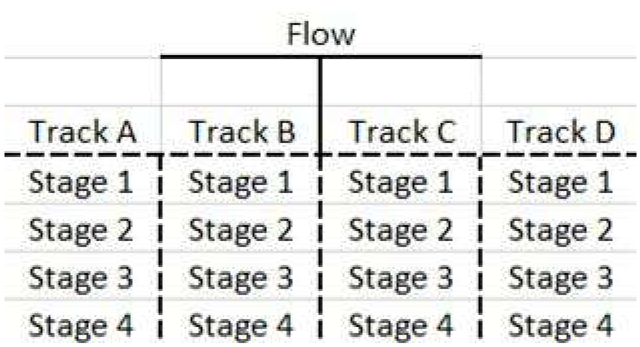
$$Converted\ Ca(OH)_2 = 244.2\ mg/L\ *\ 8.34\ lb/MG\ per\ mg/L = 2036.63\ lbs/MG$$
$$Final\ Lime\ Demand = 2036.63\ lbs/MG\ *\ 9.908\ MGD = 20,178.91\ lbs$$

Results from the overall lime calculations indicate that, at a total water demand of 9.908 MGD, approximately 20,180 pounds of lime will need to be added to the water treatment per day.

Mixing

Before calculating the mixing and flocculation basins, the stage and track quantities must be configured. For this case, four flocculation tracks were used and each track contained four individual stages. Figure 1.4 below gives a basic visual of the system.

Figure 1.4 Visual of Mixing System



The water temperature was assumed to be 70 degrees fahrenheit, the system detention time was 40 minutes in total (10 minutes per stage), and the retention times were as follows: G1=32 s^{-1}, G2=31 s^{-1}, G3=29 s^{-1}, and G4=28 s^{-1}. Using the approximate water demand 9,900,000 gal/d (1,323,440 ft^3/d), the tank volume was calculated using the following equation:

$$Volume = * = \frac{(1{,}323{,}437.5\ \frac{ft^3}{day})}{4\ tracks} * \frac{40\ min}{4\ stages} * \frac{1\ day}{1440\ min} = 2,297.63 ft^3$$

Then, using the equation listed below, the root mean square velocity (G) was determined.

$$G_{mean} = \frac{S_1+S_2+S_3+S_4}{4} = \frac{32+31+29+28}{4} = 30\ s^{-1}$$

Next, the required power for the system was calculated. This was done for each of the four stages, as each stage is associated with a different root mean square velocity value. It is important to note that since the water temperature was assumed to be 70 degrees fahrenheit, the value for the absolute viscosity (μ) is $2.05 * 10^{-5} \frac{lb*sec}{ft^2}$.

Using the equation below, results can be found in Table 1.5 to show the calculated power values for each of the four stage:

$$G = \sqrt{\frac{P}{\mu * v}} \rightarrow P = (\mu * v)G^2 = (2.05 * 10^{-5} \frac{lb*sec}{ft^2} * 2,297.63\, ft^3)G^2$$

Table 1.5 Power System for Flocculation Stages

Stage	Root Mean Square Velocity	Power
1	G1 = 32	$48.2\ \frac{lb*ft}{s}$
2	G2 = 31	$45.3\ \frac{lb*ft}{s}$
3	G3 = 29	$39.6\ \frac{lb*ft}{s}$
4	G4 = 28	$36.9\ \frac{lb*ft}{s}$

Flocculation

The effective tank diameter was calculated to begin the flocculation basin calculations. The individual flocculation chamber volume is 2,300 ft^2: the depth was chosen to be 10 feet, the width was 12 feet and the length was 19 feet. The effective tank diameter was calculated using the following equation:

$$T_e = 1.13\sqrt{(W * L)} = 1.13\sqrt{(12 * 19)} = 17.06\, feet$$

The next calculation was the power dissipated by the paddle flocculator, but the paddle velocity must be calculated beforehand. The rotational velocity was determined to be four rotations per minute and the distance from the shaft to the paddle center (r) is 2 feet.

$$Paddle\ Velocity\ =\ 2\pi rR\ = (2\pi)(2ft)(4rpm * \frac{1\,min}{60s}) = 0.838\ \frac{ft}{s}$$

The water was assumed to move at approximately 80% of the speed of the paddles:

$$Water\ Velocity\ =\ Paddle\ Velocity * 0.80\ =\ 0.838\frac{ft}{s} * 0.8 = 0.670\frac{ft}{s}$$

$$Power = \frac{Drag\ Coefficient\ (C_d)*Padde\ area\ (A)*Water\ density\ (\rho)*[(Paddle\ velocity\ (v_p)*(1-k)]^3}{2}$$

$$= \frac{(1.8)(0.5)(998)[(0.838)(1-0.35)]^3}{2} = 72.58\frac{lb*ft}{s}$$

Where k is a constant that is assumed to be 0.35 in this instance. Additionally, Cd is a constant 1.8. The density of water (ρ) at the temperature of 70 degrees fahrenheit is 998. The next calculation was for the power required for a flocculation tank with "n" symmetrical paddles. For this design, there are four flocculation chambers, each with four paddles. The paddle dimensions were determined to be 0.25 feet x 2 feet. Their power was calculated using the following equation:

$$Power = \frac{total\ paddles\ (n)}{2} * (C_d A_i \rho)(1-k)^3(2\pi N)^3$$

$$= \frac{16}{2} * (1.8 * 0.5 * 998)(1-0.35)^3(2\pi * \frac{4\frac{rev}{min}}{60\frac{sec}{min}})^3 * (2ft)^3 = 1160\frac{lb*ft}{s}$$

Sedimentation

In order to calculate the design criteria for the sedimentation tanks, it is important to consider the different parameters given for rectangular basins such as overflow rate, depth, weir loading, horizontal velocity, detention time, length:width ratio, and length:depth ratio. Calculations are based off of 2 sedimentation tanks, each with a 150' length, 30' width, and 10' depth. The overall volume of these tanks is 90,000 ft^3 or 1,346,400 gallons. The water demand flow is calculated to be 9,908,885 gallons per day or 919.94 ft^3 per minute. The weir length is 500 ft.

Detention time is calculated through the following equation:

$$Detention\ Time\ =\ \frac{Volume\ (V)\ (gallons)}{Flow\ (Q)\ (gal/d)} = \frac{1{,}346{,}400\ gallons}{9{,}908{,}885\ gal/d} =\ 3.26\ hours\ (meets\ 1-4\ hour\ criteria)$$

Overflow rate is calculated through the following equation:

$$Overflow\ Rate\ =\ \frac{Flow\ (Q)\ (gal/d)}{Surface\ Area\ (A)\ (ft^2)} = \frac{9{,}908{,}885\ gal/d}{9{,}000\,ft^2}\ =\ 1,100.99\ gpd/ft^2\ (meets\ 500-1400\ gpd/ft^2\ criteria)$$

Horizontal velocity is calculated through the following equation:

$$Horizontal\ Velocity\ =\ \frac{Flow\ (Q)\ (ft^3/min)}{Cross\text{-}Section\ Area\ (A)\ (ft^2)} = \frac{919.943\,ft^3/min}{300\,ft^2}\ =\ 3.07\,ft/min\ (meets\ 1-4\,ft/min\ criteria)$$

Weir loading is calculated through the following equation:

$$Weir\ Loading = \frac{Flow\ (Q)\ (gal/d)}{Length\ (ft)} = \frac{9{,}908{,}885\ gal/d}{500\ ft} = 19{,}817.77\ gpd/ft^2\ (meets\ 18{,}000 - 24{,}000\ gpd/ft^2\ criteria)$$

The length:width ratio is calculated through the following equation:

$$L : W = \frac{Length}{Width} = \frac{150\ ft}{30\ ft} = 5\ (meets\ greater\ than\ or\ equal\ to\ 5\ design\ criteria)$$

The length:depth ratio is calculated through the following equation:

$$L : W = \frac{Length}{Depth} = \frac{150\ ft}{10\ ft} = 15\ (meets\ greater\ than\ or\ equal\ to\ 15\ design\ criteria)$$

Iron and Manganese

When calculating the dosage of potassium permanganate required for iron and manganese oxidation, the oxidation reactions are as follows. For iron, the following reaction is used:

$$3Fe^{2+} + MnO_4^{-} \rightarrow 3Fe^{3+} + MnO_2$$

For manganese, the following reactions are used:

$$3Mn^{2+} + 2MnO_4^{-} \rightarrow 5MnO_2$$

The following equations are used to convert iron and manganese:

$$\frac{mg/l\ Fe}{56 mg/mmole\ Fe} * \frac{mmole\ KMnO_4}{mmole\ Fe} * \frac{mg\ KMnO_4}{mmole\ KMnO_4} = mg/l\ KMnO_4$$

$$\frac{mg/l\ Mn}{55 mg/mmole\ Mn} * \frac{mmole\ KMnO_4}{mmole\ Mn} * \frac{mg\ KMnO_4}{mmole\ KMnO_4} = mg/l\ KMnO_4$$

$$\frac{2.8\ mg/l\ Fe}{56 mg/mmole\ Fe} * \frac{1\ mmole\ KMnO_4}{3\ mmole\ Fe} * \frac{158\ mg\ KMnO_4}{1\ mmole\ KMnO_4} = 2.633\ mg/l\ KMnO_4$$

$$\frac{1.2\ mg/l\ Mn}{55 mg/mmole\ Mn} * \frac{2\ mmole\ KMnO_4}{3\ mmole\ Mn} * \frac{158\ mg\ KMnO_4}{1\ mmole\ KMnO_4} = 2.298\ mg/l\ KMnO_4$$

$$2.633\ mg/l\ KMnO_4 + 2.298\ mg/l\ KMnO_4 = 4.931\ mg/l\ KMnO_4$$

Fluosilicic acid

When calculating the dosage of chemicals required for water treatment, it is important to first consider the recommended fluoride to be used. Big Bluff has an annual average daily temperature of 15 °C or approximately 59 °F. In Viessman and Hammer's Water Supply and Pollution Control 7th Edition Textbook, Table 11.11 Recommended Fluoride Limits for Public Drinking Water Supplies provides the necessary information to calculate fluoride ion concentrations. As a result, this table indicates that, when using an annual average temperature of 59 °F, the optimum recommended limit of fluoride ion concentrations can be calculated as 1.0 mg/l. Next, Table 11.12 Common Chemicals Used in the Fluoridation of Drinking Water can be used to gather information regarding Fluosilicic Acid, such as fluoride ion percentage, and commercial purity percentage (Viessman and Hammer 2005). The chemical dosage can then be calculated using the following formula:

$$dosage \ = \ \frac{X \ mg/l * 8.34 \ lb/MG \ per \ mg/l}{Commercial \ Purity \ (\%) * Fluoride \ ion \ (\%)}$$

When using the values of 26% commercial purity, 79% fluoride ion, and 1 mg/l, the following calculations can be completed:

$$dosage \ = \ \frac{1 \ mg/l * 8.34 \ lb/MG \ per \ mg/l}{0.26 * 0.79} \ = \ 40.6 \ lb/mil \ gal$$

Using the estimated water demand of 9,908,885 GPD, the total chemical dosage of fluosilicic acid is calculated to be 402.3 lbs.

Dual-media coal-sand filter

$$\frac{9908885 \ GPD}{75' * 30' * 1440 min/day} \ = \ 3.06 \ gal/min/ft^2$$

$$15 \ gal/min/ft^2 * 75' * 30' * 15 \ min = 337500 \ gal$$

$$\frac{337500 gal}{9908885 gal} * 100 = 3.41\%$$

Chlorine

When calculating the required chlorine for disinfection, the suggested dose is 3 mg/L (CDC 2013). The following equation is used to calculate the weight (lbs) of 10% available:

$$lbs \ 100\% \ available \ Cl_2 \ = volume \ (gal/d) * \ dose \ (mg/l) \ * \ density \ of \ water \ (lbs/gal)$$

$$lbs \ 100\% \ available \ Cl_2 \ = \ \frac{9908885 \ GPD}{1000000} * 3 \ mg/l \ * \ \frac{8.34 \ lb}{gal} = 249.41 \text{ lb}$$

$$lbs \ 10\% \ available \ Cl_2 \ \frac{248.41 \ lb}{0.1} = 2494.07 \text{ lbs chlorine}$$

CAD Drawings

See attached 11 x 17 drawing for schematic flow diagram.

Appendix

References

Action MFG. (2019). "Water Usage Rough Estimates." *Action Manufacturing & Supply, Inc.*, <https://actionmfg.com/water-usage-rough-estimates/> (February 26, 2020).

Broward County Florida. (2012). "Equivalent Residential Unit Factors." *Public Works Department,* <http://www.broward.org/WaterServices/Documents/EquivalentResidential.pdf> (March 10, 2020).

CDC. (2013). "Disinfection with Chlorine." *Centers for Disease Control and Prevention*, <https://www.cdc.gov/healthywater/drinking/public/chlorine-disinfection.html> (March 22, 2020).

Emrath, P. (2017). "Residential Water Use." *National Association of Home Builders*, <https://www.nahbclassic.org/generic.aspx?sectionID=734&genericContentID=259397> (February 27, 2020).

Flusberg, M. (2016). "Water, Water Everywhere…and 10 Ways for Restaurants to Stem the Flow." *Powerhouse Dynamics*, <https://powerhousedynamics.com/resources/white-papers/water-water-everywhere-and-10-ways-restaurants-stem-flow/> (March 11, 2019).

Home Water Works. (2019). "Clothes Washer." *Alliance for Water Efficiency,* <https://www.home-water-works.org/indoor-use/clothes-washer> (March 21, 2020).

Maglionico, M., Stojkov, I. (2015). "Water Consumption in a Public Swimming Pool." *International Water Association Publications*, <https://iwaponline.com/ws/article-abstract/15/6/1304/28080/Water-consumption-in-a-public-swimming-pool?redirectedFrom=fulltext> (March 21, 2020).

Viessman, W., and Hammer, M. (2002). *Water Supply and Pollution Control,* Pearson, Upper Saddle River, New Jersey.