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Historical Evolution of Design and Supply of Drinking Water Treatment Plant for the City of Bethlehem, 1741-Present

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Executive Summary

The purpose of this document is to provide a detailed account of the history of the water supply for the city of Bethlehem. This report begins with the settlement of the Moravians in the area, their need for water and the solutions they developed to meet their needs. It explains why Bethlehem water sources were switched, and how contamination, increasing population and water demands affected Bethlehem and its water supply. The document also introduces South Bethlehem and their water system. New projects that were pursued by Bethlehem are discussed, with specific reasons for the change in technology. Specific characteristics of the systems and technologies are discussed from an engineering standpoint. The characteristics are then further analyzed in regard to how specifications met the requirements and needs of the people of the city.

Overall this report concludes that throughout the history of Bethlehem, water resources provided a significant role in the development of the city. Moravians chose to settle in the Bethlehem area because of its abundant supply of water. The growth of the city in population and industry was guided on multiple occasions by the availability of water. For the most part, the city engineers and city officials have met the water needs and standards required by the government and Bethlehem's citizens.

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1741: Settlement of Bethlehem

Bethlehem was founded in 1741 by the Moravians who were searching for religious freedom. They settled on a slope by the Lehigh River where a "copious spring gushed out of the limestone" at an estimated rate of 800 gallons per minute (Green 1933, Bethlehem of PA 1968). This spring was an underground stream that rose to the surface as a result of artesian pressure and it served as Bethlehem's water source for almost 200 years (ACS, Bethlehem of PA 1968). Even during droughts, the flow was estimated to be 777,700 gallons per day (Rau 1877).

The dependable spring was the only source of water for the town, and therefore was well guarded. A fence was erected to guard the spring in 1747. Matthew Weiss and Joseph Powell were authorized to "clean the pool by the light of the moon" as a part of a superstitious practice to ensure that the spring would not run dry (ACS).

Until 1748, everyone carried their own water from the spring for domestic use. From 1748 to 1755, water haulers, also known as Aquarii, were delegated to distribute water using a cart and pails. However, this process was slow and difficult since the spring was at the bottom of the hill and the town was above it (Hein 2016).

1754: Christiansen's First Pump System

In 1751, a millwright named Hans Christiansen arrived in Bethlehem with "rare mechanical abilities." He realized that the water wheel in the bark crushing mill could be used to pump water up to the village. This realization eventually led to the erection of the first pumping equipment used for municipal water supply in the 13 colonies. For this significance, the Bethlehem waterworks are now a National Historic Civil Engineering Landmark, a National Historic Landmark and an American Water Landmark (Hein 2016). Construction of the pumping system started in the spring of 1754 with the erection of a 78 ft water tower where the central Moravian church now stands. Another tank was built in front of the girls' school and a 19 ft by 22 ft frame was built over the spring to enclose the machinery (Green 1933). Figure 1 shows the structure that is currently on top of the spring. While the spring does not come to the surface today, this is a representation of what the frame would have looked like in 1754.

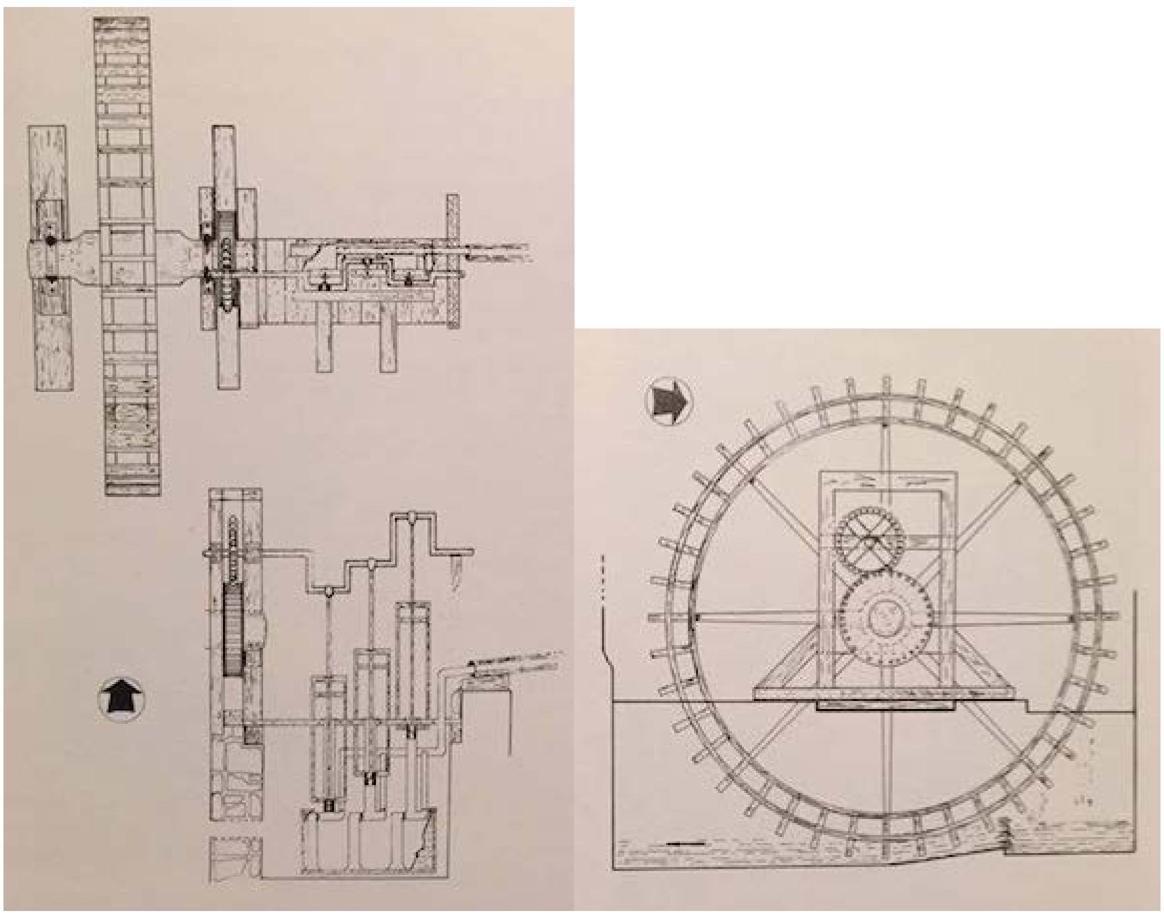
Figure 1: Representation of 1754 Frame Springhouse

John Boehner, a West India Missionary visiting Bethlehem, helped with a model for the first pump. The pump was made of lignum vitae and its cylinder had a 5 in diameter. The pump was first tested in June of 1754. During the first trial, water shot in a jet as high as the adjoining houses (Green 1933).

During the winter of 1754, logs were bored to make the pipes for water distribution. On May 27, 1755, water flowed through the system for the first time, putting an end to the water carriers. In the system, the spring water flowed into a cistern and then was pumped up to the water tower through wooden conduits. According to the Moravian diary, the wood used was hemlock and gumwood. However, a later Pennsylvania State report said it was unlikely that gumwood was used due to its scarcity in the area, and that they possibly meant gun wood, also known as black walnut (Green 1933). Bursting pipes caused frequent flow interruptions because the wooden pipes could not handle the high pressure (Adams 1898).

1761: Christiansen's Second Pump System

Hans Christiansen wanted to improve the system, so in 1761 construction began on a larger building and more powerful machinery. A two story, 22 ft by 30 ft stone building was constructed to the south of the original frame building. Once this permanent structure was built, it was used as a refrigerator to store vegetables and dairy products (Hein, 2016). On July 6, 1762, the three new single-acting force pumps were put into use.



Figures 2 (left) and 3 (right): Depictions of the Three Single Acting Force Pumps and the Water Wheel That Powers Them as of 1762

These pumps work by a triple crank that moved the three pistons at the same time (Green 1933). These pumps go up and down to create suction and then pressure that sends water up the hill (Hein 2016). The pumps were calculated to raise the water 70 ft, which was later increased to 112 ft (Adams 1898).

Several more cisterns were built in the vicinity of principal dwellings that received water from the main water tower by gravity. These cisterns were located by the Widow's House; the Apothecary; the Sun Tavern; the Brethren’s house, from which pipes distributed water to the stable, hattery and milk cellar; the Seminary; on Market Street 50 ft east of Main; and in the farm building. Visitors to Bethlehem, including John Adams and George Washington, were very impressed with the system (Green 1933). John Adams wrote a letter to his wife Abigail on February 7, 1777 explaining what he saw in Bethlehem:

> “They have carried the mechanical arts to greater perfection here than in any place which I have seen, they have a set of pumps which go by water, which force the water up...from the river to the top of the hill, near a hundred feet, and to the top of a little building in the shape of a pyramid or obelisk, which stands upon the top of the hill, and is twenty or thirty feet high. From this fountain water is conveyed in pipes to every part of the town” (Adams 1876).

1786-1813: System Improvements

In 1786, the “gumwood” mains were replaced by lead pipes and the pitch pine conduits of Main Street from Market Street to the Sun Tavern were replaced by new logs. In 1796, the logs were also replaced by lead pipes (Green 1933).

In 1803, the original water tower was taken down so a larger church could be built in the same location. A larger, octagonal 15 ft tower was built 112 ft above the spring and received water directly from the lead mains, and was then sent to the other cisterns (Rau 1877).

In 1813, iron pipes were introduced, which were packed at the connections with leather, then joined and tightened with screw clamps by their flanged ends (Green 1933). The pipes were laid with little regard for the amount of friction that existed. Throughout the entire town, the pipes varied in size from 3 to 12 in diameter, and at varying depths from 18 in to 5 ft (Wells 1885). Two more reservoirs were also built on Market Street in 1813. One was a reserve in case of accident or extensive fire (Rau 1877).

1831-1873: New pumps and improvements

Christiansen's triple pumps had been in use for 70 years and in 1831 were replaced by larger double-acting pumps housed in the bark crushing mill. These double-acting pumps were in use until 1873 (Miller 1888).

A reservoir was built on Broad Street in 1832 on more elevated ground to replace the water tower. This reservoir became useless in 1871 when a new iron reservoir was built 149 ft above the water works with a pressure of 80 lbs (Adams 1898).

Up until 1845, Bethlehem had been a closed community with the Moravian Church owning all the land. But in 1845, the Church started selling some property to non-Moravians, and the population started to grow. In the same year, Bethlehem was incorporated as a borough, and Bethlehem Water Co. was incorporated to manage and distribute the spring water (City of Bethlehem, Adams 1898). In May of 1872, the water company was bought out by the Borough Council (Adams 1898).

In 1873, a Cameron pump was added, in addition to a Worthington steam pump to increase the supply capacity (Miller 1888). The Cameron pump had a maximum capacity of 800,000 gallons per day. It had a double-acting cylinder with a 12 in diameter, and raised 18 gallons of water per stroke at 20 strokes per minute -- ultimately distributing over 500,000 gallons in 24 hours (Adams 1898). The Worthington pump also pumped 500,000 gallons per day. As a further improvement, the wooden conduit from the spring to the cistern was replaced by 18 in iron pipe (Adams 1898).

1885-1892: South Bethlehem's Water Supply

At this point, the Lehigh River was the water source for South Bethlehem. While the river water was soft and normally did not have a disagreeable odor or taste, sewage contamination from towns upstream caused high bacteria counts; in the spring, water was black from coal mining; and water was sometimes reddish due to steel mill waste (Gressit 1908).

In 1885, the lower 5 million gallon reservoir was constructed behind present day St. Luke’s Hospital. The division wall running across the middle existed because it was previously used as two reservoirs. The half nearest to the river was used as a subsidence reservoir, while the other half was used as a storage reservoir. No dirt or refuse except that which was thrown in or windborne could pollute the reservoir. Additionally, the slopes were whitewashed so the cleanliness of the water could be easily seen (Hurst 1907).

During the same year, the pumping station was constructed about a mile upstream of the Lehigh Valley Railroad Union Station (Hurst 1907, Jackson 1908). In 1886, a 2.5 million gallon single-acting vertical crank and flywheel Dixon pump was installed along with two 100 horsepower boilers manufactured by McKee and Wilson (Jackson 1908, Hurst 1907). The Bethlehem South Gas and Water Company pumped water from the Lehigh River into the lower reservoir at an elevation of 245 ft, allowed suspended contaminants to settle, and then distributed the water to South Bethlehem by gravity (Hurst 1907, Gressit 1908).

In 1888, the water quality was already questionable due to discharge from Allentown and Miller suggested that the Lehigh River source should be moved above Allentown to avoid this contamination from sewage (Miller 1888). In 1891, construction was completed on a new earthen uncovered reservoir with a capacity of 14 million gallons; however, it was found necessary in practice to carry only 12 million gallons (Andrews & Lowry 2013, Hurst 1907). At mean water level this reservoir was 420 ft long by 220 ft wide, occupying 4.86 acres. The lining consisted of concrete 6 in deep resting on a layer of clay puddle 18 in deep. Before the clay puddle had been laid, the earth had been rammed by workmen. In 1892, an additional 5 million gallon horizontal cross-compound double-acting high duty Holly pumping engine was installed along with a third 100 horsepower boiler (Hurst 1907, Jackson 1908).

1890s: Increasing Water Supply on the North Side

In 1889, a new pump room was built and a new Dean pump was installed with compound cylinders of 16 and 24 in diameter. The pump was tested around 1898 and found to pump 105,767 cubic ft of water in 10 hours. At this time, the Cameron and Worthington pumps were still in good repair but were only used in case of high demand or if repairs to the Dean pump were necessary (Adams 1898). A new iron tank of 50 by 50 ft was built as well (Adams 1898).

More water was necessary in 1890 due to population growth, so an artesian well was utilized. An air compressor that worked in connection with the artesian well was installed in 1896 and had a capacity of 500 gallons per minute. The artesian well of 250 ft was drilled 30 ft from the water works building. It was surrounded by an elliptical cement lined masonry basin 27 ft by 20 ft and 30 ft deep. The air compressor sent air 118 ft down a pipe where it came in contact with the water, and then forced it up through a 5 in pipe. The water fell into the basin surrounding the well and then flowed through 18 in pipes to the spring where it mixed to increase flow. The spring was 350 ft from this building and was estimated in 1898 to be 40 ft by 16 ft and 5 ft deep (Adams 1898). The water then flowed to the cistern in the pumping station, and through the mains into the 50 by 50 ft tank where it could be drawn off. A report by R.E. Newmeyer said it would have been impossible to furnish the amount of water necessary without the supplementary amount from the artesian well (Adams 1898).

Adams reported the daily average amount of water pumped for several years, shown in Table 1, and noted that the steady increase from year to year indicated that more pumps might be necessary to supplement the present supply. As of 1898, the maximum daily amount of water pumped was on January 18, 1895, a total of 1,021,296 gallons. At that time it was necessary to use the Worthington pump to aid the Dean pump.

Table 1: Daily Average Amount of Water Pumped for Several Years in Gallons

Year	Daily Average of Water Pumped (gal)
1874	105,000
1887	482,000
1888	520,771
1894	771,570
1895	833,205

(Adams 1898)

1898: North Side Spring Sanitation

The Bethlehem spring was at about the same level as the Monocacy Creek and seemed to be the natural drainage for the region. At this time, Bethlehem and West Bethlehem had no sewage system except for surface drainage and cesspools; therefore, sewage had been percolating into the soft limestone strata for hundreds of years all around the spring. Yet, the spring seemed to be clean. Adams surmised that the spring water most likely flowed for a great distance under impervious strata in order to remain clean, otherwise the spring would have been condemned years ago. As it was, the water of the spring was liable to contamination and required careful watching (Adams 1898).

In December of 1885, there was a typhoid fever outbreak and following an investigation, Dr. Weaver came to the conclusion that the outbreak was caused by contamination of the water from the Monocacy Creek. In Bath, PA, which is upstream of Bethlehem, the cesspools dump into the Monocacy Creek and could have been the source of contamination. Tests by other doctors were inconclusive as to whether this was the true cause of the outbreak (Adams 1898).

The purity of the water was continuously doubted in the following years. The medical examiner of the Lehigh district recommended a sewage system to get rid of the cesspools, but this was not feasible at the time (Adams 1898).

1904: South Bethlehem Filtration Plant

In 1904, a number of serious typhoid fever epidemics were attributed to the water supply and led to the construction of a filtration plant in South Bethlehem (Gressit 1908).

The water flowed from the river into a masonry suction well, 15 ft by 30 ft by 8 ft, and was then pumped through an 18 in diameter pipeline, 2000 ft in length, to the 12 million gallon storage reservoir 265 ft above the river (Jackson 1908). The filtration plant was built by extending an embankment at the level of the distributing reservoir and then constructing a 106 ft by 206 ft one-story brick building containing six 16 in by 182 ft concrete tanks 6 ft deep (Gressit 1908).

Water flowed from the 12 million gallon storage reservoir to the filtration building and into the bottom of the scrubbers upward through the filtering material, over the dividing wall and down through the sand filter. Water was then collected in the underdrains, running into the effluent chamber, which discharged into the distributing reservoir, flowed into the standpipe and eventually the mains (Gressit 1908, Jackson 1908). The ultimate capacity of the filter plant was 4 million gallons per day, fully satisfying the average daily demand of 2.8 million gallons per day (Jackson 1908).

The first section of these tanks, the first 37 ft-6 in, was a scrubber to prepare the water for sand filtration (Gressit 1908). Operating at 28 million gallons per acre per day, the scrubbers had a bacterial efficiency of 75 percent (Jackson 1908). The scrubber's first layer at the bottom was made up of 3 in river gravel. The remainder was filled with 3 in coke. Four layers of 1/14 in coke, with an aggregate thickness of 2 ft was placed over the 3 in coke. In each of these layers were rows of slate about the size of roof slates. The slate rows in the lower layers were placed longitudinally, while those in the layers above alternate between a transverse or longitudinal placement. The slates in the lower and upper longitudinal rows were inclined 30 degrees from zero and 180 respectively. This incline was the same for the two sets of transverse rows. These rows of inclined slate were placed to break up the currents of water and prevent channeling through which water would flow without being filtered (Gressit 1908). Over the coke containing the rows of slates were an additional 10 in of 1/14 in coke (Hurst 1907). The last layer was sponge ordinarily 18 in thick, but compressed by a cedar grating to make the total depth 4 ft-6 in (Hurst 1907, Gressit 1908). The beds were flushed once every two weeks. The sponge was lifted by hand in baskets from the bed and washed in revolving drum laundry washing machines powered by steam, then replaced by hand in the scrubber. Each bed required five laborers working for four days to place the bed out of operation, wash the 3600 lbs of sponges, replace the sponges, and then put the bed back into operation (Hurst 1907).

The preliminary filtration by the scrubbers allowed the sand filtration to remove the finest suspended matter and bacteria, operating at 7 million gallons per acre per day (Jackson 1908). The sand beds were 16 ft by 152 ft and 6 ft deep with a reinforced concrete underdrain running the full length. The bottom layer was filled with river gravel graded from 3 in stones at the bottom to 1/4 in stones at the top to a height of 18 in (Gressit 1908, Hurst 1907). Over this was two ft of washed bank sand from Birmingham, NJ, which passed through #14 sieve and was retained in sieve #80, and placed in six in layers (Hurst 1907). These beds were cleaned once every 90 days, or when head loss was about 4 ft (Gressit 1908). During the cleaning process, the water was drawn down and the dirty sand removed with shovels by men standing on a timber platform suspended close to the sand on a traveling crane in order to not compress the sand. The sand scraping started at the end of the bed farthest from the scrubbers to the depth that the sand was discolored by the sediment in the raw water. Usually 1/12 to 3 in was removed to reach the clean sand. This sand was washed and placed back on the beds. The cleaning of each bed, washing the dirty sand and replacing it required three men for about a day and a half. After the sand was replaced, filtered water was slowly admitted through the underdrain from an adjacent filter. After water was released from the scrubber, the effluent from the bed was permitted to waste for a day (Hurst 1907).

The water in the filtered water reservoir completed a full circuit, therefore there was no chance for water to remain in any part of the reservoir longer than average and allow bacteria to collect and multiply. In addition to the circulation caused by the inflow and outflow of water, in a reservoir 15 ft deep, there was also diurnal circulation due to changes in temperature. With a capacity of 5 million gallons and a daily consumption of 2.8 million gallons, the water remained in the filtered water reservoir for less than two days (Gressit 1908). The storage of the filtered water in an open reservoir was deemed acceptable because of only minute increases in bacteria, as seen in Jackson's 1908 tests; and the absence of other micro-organisms, objectionable tastes or odors found in the water (Jackson 1908). Also, taking into account the decreased mortality rate since the installation of the filtration plant, the improved bacteriological quality and appearance of the filtered water when compared to the Lehigh River, it was fair to conclude that the filtration plant was very efficient (Hurst 1907).

Throughout the whole process 98.83 percent of bacteria were removed (Hurst 1907). Average bacteria reduction at the filter outlet was 97.16 percent. However, water taken at Williams Hall on Lehigh University's campus had an average bacteria reduction of only 91.15 percent (Gressit 1908).

1912: Spring Contamination and Switch to Wells

The usage of the Bethlehem Spring and Waterworks station ultimately ended in 1912 (Hein 2016). Potability issues of the spring water catalyzed the creation of Illick's Mill and the subsequent termination of the Bethlehem Spring. However, a clamor for a new water source had reached the City Council long before the spring became non-potable.

Between 1890 and 1910, the population of the Bethlehem area, including West, South and North Bethlehem, nearly doubled from 19,823 to 32,810 inhabitants (US Census). During this period, the Bethlehem Spring still provided the amount of water needed by the residents of North and West Bethlehem and was unfailing in quality, but a desire for new water sources was becoming more apparent. The increase in water demand, in part stimulated by industrial requirements and in part due to population growth, threatened to put a strain on the water supply (Adams 1898).

In addition to population growth, there was a growing concern in the community about a variety of spring source characteristics. Not only was the location not aesthetically pleasing, but it was situated downstream from a stable, brewery and a few houses. It was believed that these businesses and residencies could contaminate the water supply with their wastewater. The fear that the spring would be polluted was exacerbated by the fact that Bethlehem did not have a drainage system to combat daily sewage as previously stated (Adams 1898).

Although the source of the spring's contamination was unknown, it was ultimately abandoned due to potability issues. The first solution was to build wells that could supplement the spring. When wells were drilled, the fears of the community were realized. As early as 1912, the city found that some well sources were contaminated and could not be used. "A 300 ft well drilled nearby in 1912 was found to be contaminated, but a 390 ft well half a mile away north at the Bethlehem Silk Company was used" (ACS). Three years later a third well was drilled in this area that could supply 2 million gallons of water per day (ACS).

In 1907, B. coli was found in the spring water. The State Health Commissioner condemned the water supply on May 27, 1907 and the Water Commission of the Town was instructed to select a new water supply. Luckily Bethlehem had already looked into new sources. In 1903, the Water Commission had been appointed to investigate a new supply; however, this Commission only did preliminary work. A new commission was appointed in 1904 after the consolidation of the two boroughs. The 1905 report came up with seven possibilities: (1) filtered Lehigh water, as supplied by the Bethlehem Water Commission or as filtered by their own plant; (2) Monocacy water filtered at their own plant; (3) water from springs adjacent to the Monocacy or in the neighborhood of the town; (4) water from the Butztown Spring offered by the Meadow Spring Water Commission; (5) driven wells in the watersheds either north or south of the town;

(6) water of streams or lakes north of the Blue Mountain; or (7) water of streams draining the south slope of the Blue Mountains. Filtered Lehigh River water and water north of Blue Mountain were eliminated due to high costs. Monocacy Creek water was hard, while springs adjacent to the Monocacy, the Butztown spring, wells north or south of the town, or streams draining the south slope of the Blue Mountain did not provide enough supply (Padgett 1909).

The Borough Engineer, R.E. Neumeyer, then suggested the filtering of the Monocacy waters at Illick's Mill. The Illick's Mill Property was 19.5 acres and 3200 ft long with the creek passing through its entire length. For 2000 ft of this length, the creek was dammed and was estimated to potentially hold 4 million gallons. It was decided that all water needed would be taken from the two wells and the creek water stored in the dam could be used as power to pump the well water to the reservoir. It was concluded that the Illick's Mill location was ideal for the following reasons: (1) the topography allowed a fair sized dam reservoir; (2) the waters of the dam could be utilized to power the pumping plant; (3) in case a filtering plant was needed, the waters of the dam could run on the filters by gravity, thus eliminating pumping costs; (4) the railroad facilities could be used for obtaining freight and coal; (5) the windings of the creek and shady banks made ideal picnic spots (Padgett 1909).

The Water Commission recommended the Illick's Mill well plan to the Town Council, who adopted it, and in 1909 the town voted on a bond issue of $175,000 for the new water supply (Padgett 1909).

1917: City of Bethlehem's Incorporation

In 1917, Bethlehem Township officially became a city that incorporated the South Bethlehem, West Bethlehem and Bethlehem regions. The city had the foresight to instruct the City Engineer to investigate new sources of water in 1918 as contamination and population growth continued to be concerns. The report concluded that the Pocono Mountains in Carbon County would serve as an ideal source of water for future generations (Bethlehem website).

At the time of the Bethlehems' unification, different parts of the town received water from different sources. Bethlehem, east of the Monocacy, gathered water from the Old Monocacy spring and Illick's Mills wells. Bethlehem, west of the Monocacy, acquired its water from the Lehigh River and in small part from South Side Mountain. South Bethlehem collected the entirety of its water from the Lehigh River. Bethlehem City Water Company, a privately owned company, had a monopoly on distributing water in the area (Andrews 2016d).

In 1918, the first city council was granted voter approval of a bond issue to purchase the Bethlehem City Water Company along with all its water mains and equipment for $1.7 million. "With this in mind, Council, as early as 1918 authorized City Engineer Robert L. Fox to make a study of the possible sources of pure water supply" (Andrews 2016d). The problem of water supply and purity had grown to be a problem for the Lehigh Valley in general as many cities gathered their water from the Lehigh River, which was also used as a discharge for waste, including coal dust, sewage, and industrial waste (Andrews 2016d). The city fathers believed that "in short, it is not safe to drink water which comes from wells and springs anywhere in the City of Bethlehem and its environs," so they agreed that, "in order to safeguard the health of our citizens, both of the present sources of water supply should be abandoned at the earliest possible date" (Andrews 2016d).

In 1929, Mr. G. Douglas Andrews, an engineer of the Public Works Administration, suggested the use of the Pohopoco Creek to provide 36 million gallons per day (MGD) for Bethlehem by constructing a 5 million gallon reservoir proximal to the Lehigh Gap. Due to The Great Depression, financially strained Bethlehem could not pursue this option. Even still, water security remained at the forefront of issues for the city. On April 15, 1937 an annual report the City Council by the City Chemist, Ralph W. Woodring, stated sternly that Bethlehem's current source of water was highly polluted. Five days later, the City Engineer, Robert L. Fox, suggested the use of Wild Creek in Carbon County as a site for a water reservoir and dam.

1938: Wild Creek Reservoir

Interestingly enough, Philadelphia had obtained a $200,000 option on the Wild Creek property in July of 1936. However, Philadelphia did not proceed with its project as Mayor Wilson of Philadelphia was unable to give this issue his attention because he fell ill. Stoken J. Drumheller, the owner of the property, cancelled the option (Andrews 2016d). The Bethlehem Municipal Water Authority was created on July 27, 1938 as a result of the 1935 General Municipal Act of Pennsylvania. The Authority set out using Fox's report to acquire permission of the State Water and Power Resources Board in Harrisburg to develop the Wild Creek Reservoir (Andrews 2016b).

Wild Creek Reservoir construction commenced on December 29, 1938 and was finished in January of 1941 (Beth-PA website). The plant was put into operation on October 1, 1941 (Brown and White 1941). The total cost of the reservoir was $4.1 million, of which the city paid $2.5 million for the plant, and the remaining 45 percent was paid for by the Public Works Administration (Brown and White 1941).

The reservoir could hold up to 3.9 billion gallons of water (Bethlehem website). It contributed a flow rate of 18 MGD (Brown and White 1941). The Wild Creek Watershed covers an area of 22 square miles with a shoreline of six miles and a 304 acre water surface area. The spillway elevation is at 820 ft. The maximum depth of the reservoir is 135 ft. The dam has a top length dimension of 1,076 ft, top width of 30 ft, and a maximum bottom width of 100 ft. The dam extends to 155 ft above the creek level (Beth-PA website). The dam was filled with 1.387 million cubic yards of earth (Brown and White 1941). A 28 mile pipeline of 24 in and 36 in diameter connects the reservoir to the city. Tunnels in which the pipe runs are 7 ft by 4 ft, running for a length of 5,890 ft (Brown and White 1941). Models for a specially designed spillway, channel and stilling basin were devised by Dr. A.T. Ippen in the Hydraulic Laboratory of Lehigh University (ACS).

Water consumption in 1938 was 4 MGD. However, water consumption dramatically increased to 17 MGD in 1944 and 20 MGD in 1955 once the Wild Creek Reservoir became operational (Beth-PA website).

1955: Penn Forest Reservoir

Due to rising water demands, the City of Bethlehem decided a second reservoir was needed to hold a greater amount of water in order to alleviate the stress on the already existing Wild Creek Reservoir. Using $8 million in bond revenues, Bethlehem built the Penn Forest Dam to handle the increased demand of a growing city. The initial construction of the Penn Forest Damn took place between 1955 and 1958. The embankment dam was 145 ft high and 1,930 ft long. Figure 4 shows the full schematic of the Earthfill Dam.

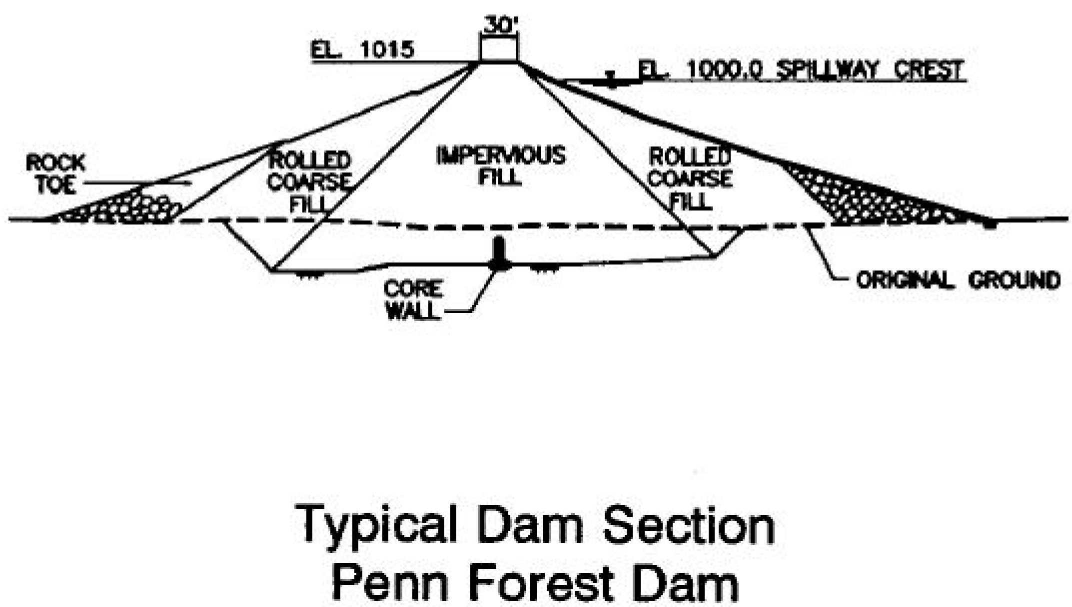
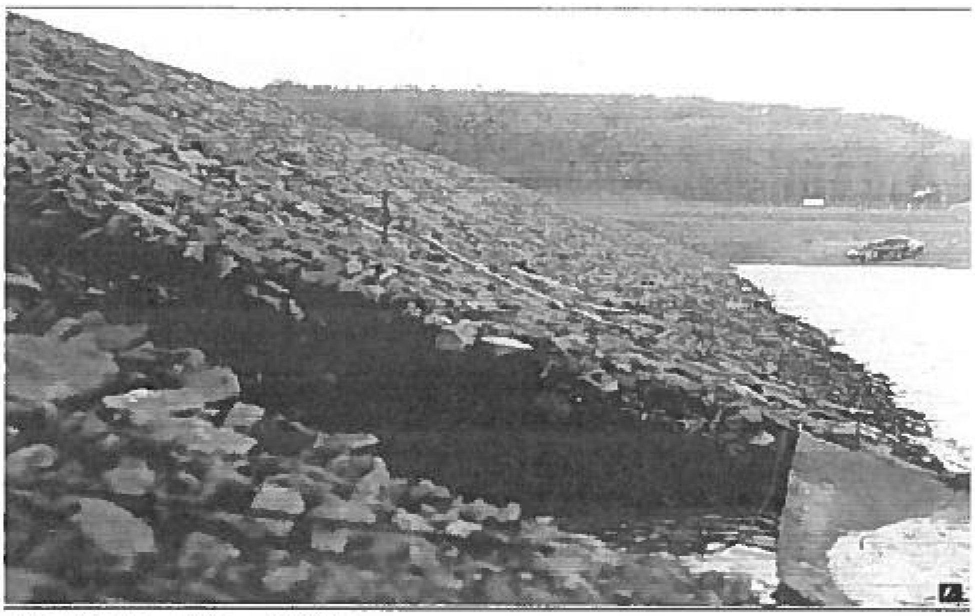


Figure 4: Original Earthfill Dam Cross Section (Bingham et al. 1996)

In April of 1960, during first impoundment, approximately 350 gallons per minute of turbid seepage water emerged from a road cut directly downstream of the dam and from weep holes in the spillway stilling basin. Over the following month, the reservoir progressively filled. On May 18, 1960, during the first filling of the reservoir up to 995.5 ft, a large sinkhole developed on the upstream embankment slope approximately 4.5 ft below the spillway height. The sinkhole was recorded to be approximately 15 ft in diameter and 15 ft deep. A dam that was designed to last 100 years failed in one month (Assad 1998). The sinkhole is pictured in Figure 5. In order to mitigate the leakage the sinkhole was filled with approximately 100 cubic yds of silt and shale. However, this filling had little to no measurable reduction on the leak. Next, the water elevation was lowered by another 26 ft below the spillway crest to decrease the head of the water in the hopes of eliminating the leak. As a result of the lowered head, the recorded leakage decreased from the initial 350 gallons per minute to 90 gallons per minute (Assad 1998).



Sinkhole, May 1960

Figure 5: Sinkhole, May 1960 (Schwinger et al. 1999)

Initial repairs included grouting of the underlying foundation rock in the vicinity of the sinkhole and pressure injecting surface-hydrated bentonite lumps and cellophane strips in the embankment to fill the voids (Schweiger et al. 1999). During drilling for grouting, engineers discovered voids in the embankment up to 18 in diameter. The foundation rock was grouted with cement in a 1:1 ratio by volume (Bingham et al. 1999). Upon completion of the grouting program seepage from the road cut alone was recorded to be 20 gallons per minute at a water elevation of 985.5 ft. Overall, the grouting program showed little improvement to overall leakage rates (Bingham et al. 1996).

In 1961 and again in 1963, additional investigations were conducted in order to evaluate subsequent steps in an attempt to repair the dam. The general consensus amongst multiple engineering firms was that the failure occurred within the mechanism of piping injection filling into the fractured rock foundation. At this time major concerns were expressed regarding the original design, construction, and subsequent emergency repairs. Documents later found that there were several issues with the grouting program. A grout curtain designed to intercept leaks in the foundation was inexplicably drilled vertically, rather than on an angle. The lack of angular slope prevented the curtain from stopping many of the leaks. It also was a single grout line, unacceptable by today's standards and probably even standards at the time, Sherman said (Assad 1998). In addition, later investigations proved the grouting was low quality, as it contained too much sand, which resulted in a less effective cover. Evidence of poor workmanship continued to appear years later with the discovery of tree limbs, roots, stumps and large rocks used in the dam fill. Ultimately, it was discovered in early documentation of dam construction that the leak was discovered and the embankment was built on top of the leaking base without ever fixing it (Assad 1998).

As a safety precaution, one of the main engineering firms conducting the investigation, Gannet Fleming, recommended a controlled refilling of the reservoir in order to determine further repair needs. A controlled filling program was implemented in 1964 after the installation of an extensive embankment and foundation instrumentation program consisting of 275 piezometers, several weirs to monitor seepage, and a network of survey monuments in the embankment (Bingham et al. 1999). After a five year filling period that ended in 1969, the water elevation was back to the originally designed spillway crest of 1000 ft. Although there were noticeable fluctuations in water seepage throughout this period, these were not significant enough to cause alarm or encourage further repairs. On October 3, 1969, almost ten years after the initial construction of the dam, the total measured seepage downstream of the reservoir was approximately 450 gallons per minute (Bingham et al. 1999).

1960s: System Improvements

In 1964, $2.8 million in bonds were issued to cover the cost of major improvements to the system and improved water service. This included a 42 in steel transmission main paralleling the existing 30 in Wild Creek transmission main for a length of 23,000 ft, which when completed in 1968 increased transmission capacity from 22 to 29 MGD. All water delivered was not metered in 1964; the bond issue facilitated the reimbursement of the City for the cost of meters and their installation. In 1965, feeder mains were installed and the 5 million gallon Southeast Low Service Reservoir was completed. The bonds also included funds to finance reforestation of 2,300 acres in the Wild Creek watershed destroyed in the 1963 forest fire; reforestation was completed in 1968 (Andrews 2003).

In 1967, $3.5 million was taken out in water revenue bonds to finance additional improvements to the system, primarily the Tunkhannock Creek addition to the Wild Creek water supply. Completed in 1968, the Tunkhannock addition cost $3.4 million in total; a $1.5 million grant from the federal government was used for this project (Andrews 2003). The Tunkhannock Creek on-stream intake controls diversion of water from a 8.6 square mile watershed to the Penn Forest Reservoir through 8.5 miles of 42 in and 36 in mains (Andrews & Lowry 2013). This addition allowed 12 MGD average flow to be added to the Wild Creek water supply, though water is only taken from the creek during the winter months and spring runoff due to water quality issues. This bond series also included funds for the construction of the parallel 36 in transmission main under the Beltzville reservoir in 1968 and instrumentation telemetering and automation improvements designed and installed in 1970 (Andrews 2003).

In 1965, the 12 million gallon reservoir previously mentioned was lined with gunite. In 1979, a flexible, plastic-vinyl liner and cover were also installed in this reservoir (Andrews & Lowry 2013).

1983: Improvements of the 2 Million Gallon Reservoir

The 2 million gallon reservoir was a dual chamber basin originally constructed as a reinforced concrete open reservoir. In 1983, this reservoir was roofed with precast concrete sections and covered with a rubber membrane weighed down by river rock. Additional, more recent repairs included a new roof and gutters, waterproofing of the interior concrete walls and floor, patching and painting of the outside concrete and brick, and replacement of the east and west sluice gates (Andrews & Lowry 2013).

1990: Construction of the Northeast Tank

The 5 million gallon Northeast Tank was constructed in 1990 and placed into service in 1991 (Andrews & Lowry 2013).

1994: Opening of Plant

Change in EPA Regulations

The Disinfection Byproducts Rule was put into effect in the mid 1980s regarding the control of trihalomethane (THM) formation, setting limits on disinfection byproducts, and changed laboratory analysis requirements. However, no operation changes were required for the City of Bethlehem because of the exceptional source water quality. Shortly after, the Safe Drinking Water Act was amended to include the Surface Water Treatment Rules mandating "that all surface water supplied be filtered by December 31, 1995" (Andrews 2016b). The Notice of Proposed Rulemaking was released in the late 1980s; this regulation greatly influenced how the filtration plant was designed and built (Andrews 2016b). Construction of the current Filtration

Plant began February 12, 1992 (Brown 2016b). According to the EPA, the Surface Water Treatment Rule "establishes maximum contaminant level goals (MCLGs) for viruses, bacteria and *Giardia lamblia*" (USEPA 2015). The Interim Enhanced Surface Water Treatment Rule was added in December of 1998 to include a MCLG of zero for Cryptosporidium, as well as requirements for covers on new finished water reservoirs and sanitary surveys (US EPA 2015).

Direct Filtration System

On October 13, 1994, the Bethlehem Water Treatment Plant came online equipped with a filtration system designed to meet the requirements of the Safe Drinking Water Act. It is a direct filtration treatment plant, and therefore does not include a sedimentation process in the plant. Gravity flow provides water from the reservoirs to the plant and from the plant to North Bethlehem, so no pumping is required. However, pumps are needed to service South Bethlehem. The location of the facility was chosen for its elevation so that gravity flow could be used as it decreases the energy demand associated with pumping. The trajectory of the water from Wild Creek to the Bethlehem Filtration Plant and then on to the consumers can be seen in Figure 6 (Brown 2016a).

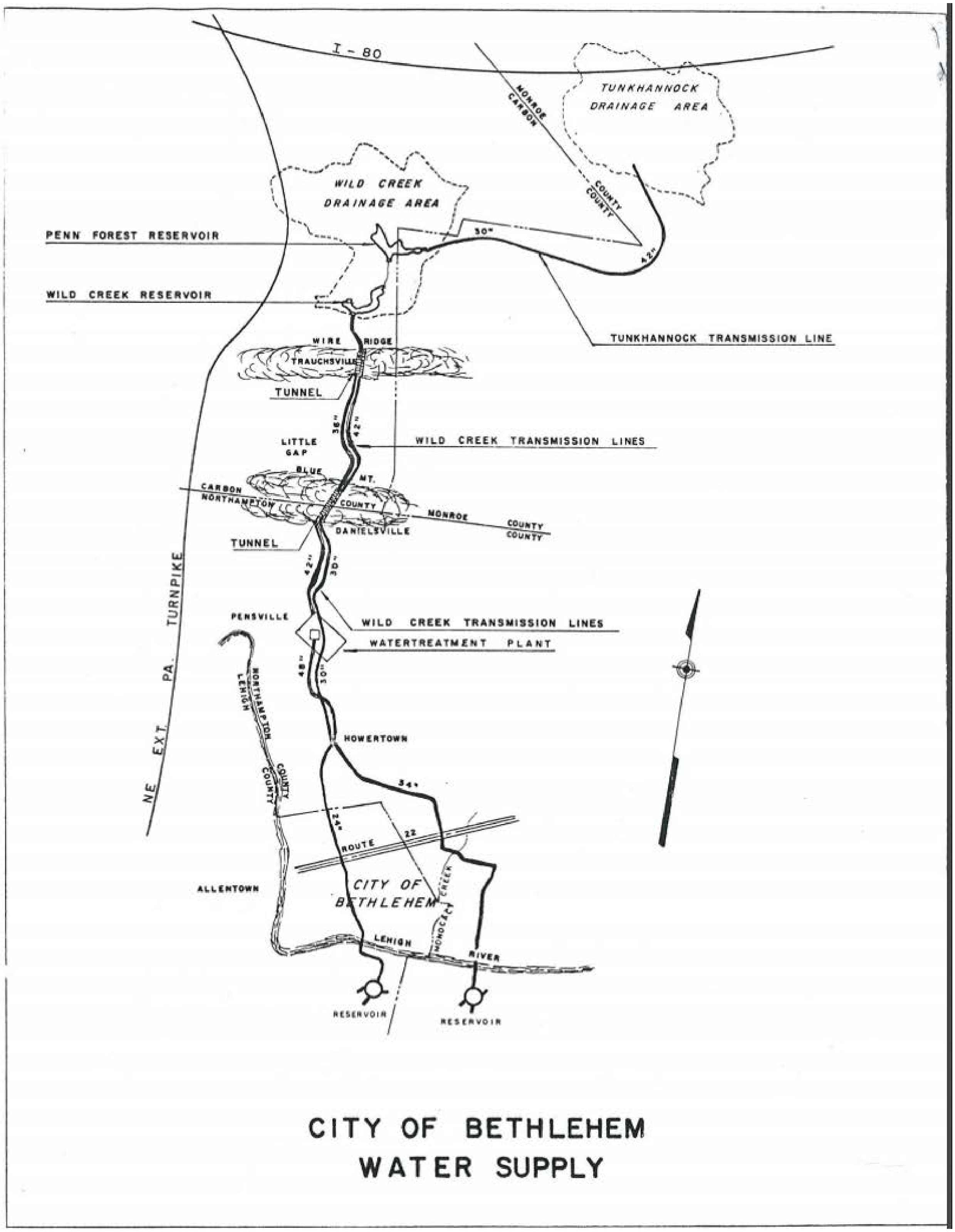


Figure 6: City of Bethlehem Water Supply

Originally the system was designed for a maximum of 65 MGD when the source water had a turbidity 0.2 NTU. However with the increase in turbidity of the source water and redesign of the filtration system, the system now handles a maximum of approximately 28 MGD. On average during the year, 13 to 14 MGD of water is produced by the plant. In the summer, 20 MGD is produced, but demand is reduced in the winter to 11 or 12 MGD. During the day, on average 15 MGD are produced, while at night it decreases to 8 MGD. Flow is raised to 21 MGD in order to scour the mains (Brown 2016a).

Water first enters the facility at a flow control building. Since no pumps are used, the amount of water let into the facility must be controlled using control valves. The water is then pretreated with chemicals. At this stage, surface water from the lagoon is recycled into the system, as described below. Flocculation is then utilized to clump particles together so that they are more easily filtered out. During the flocculation stage, large windmill-like mixers are used to churn the particles and the gaseous chlorine. Settling is not used because of the low turbidity of the source water and the extended time that would be required for settling, as seen in Figure 7 (Brown 2016a). As of 2002, the Interim Enhanced Surface Water Treatment Rule set a Maximum Combined Filter Effluent (CFE) turbidity of 1 NTU. The turbidity must be tested every 4 hours, before and after filtration and any exceedances must be reported within 24 hours (USEPA 2004).

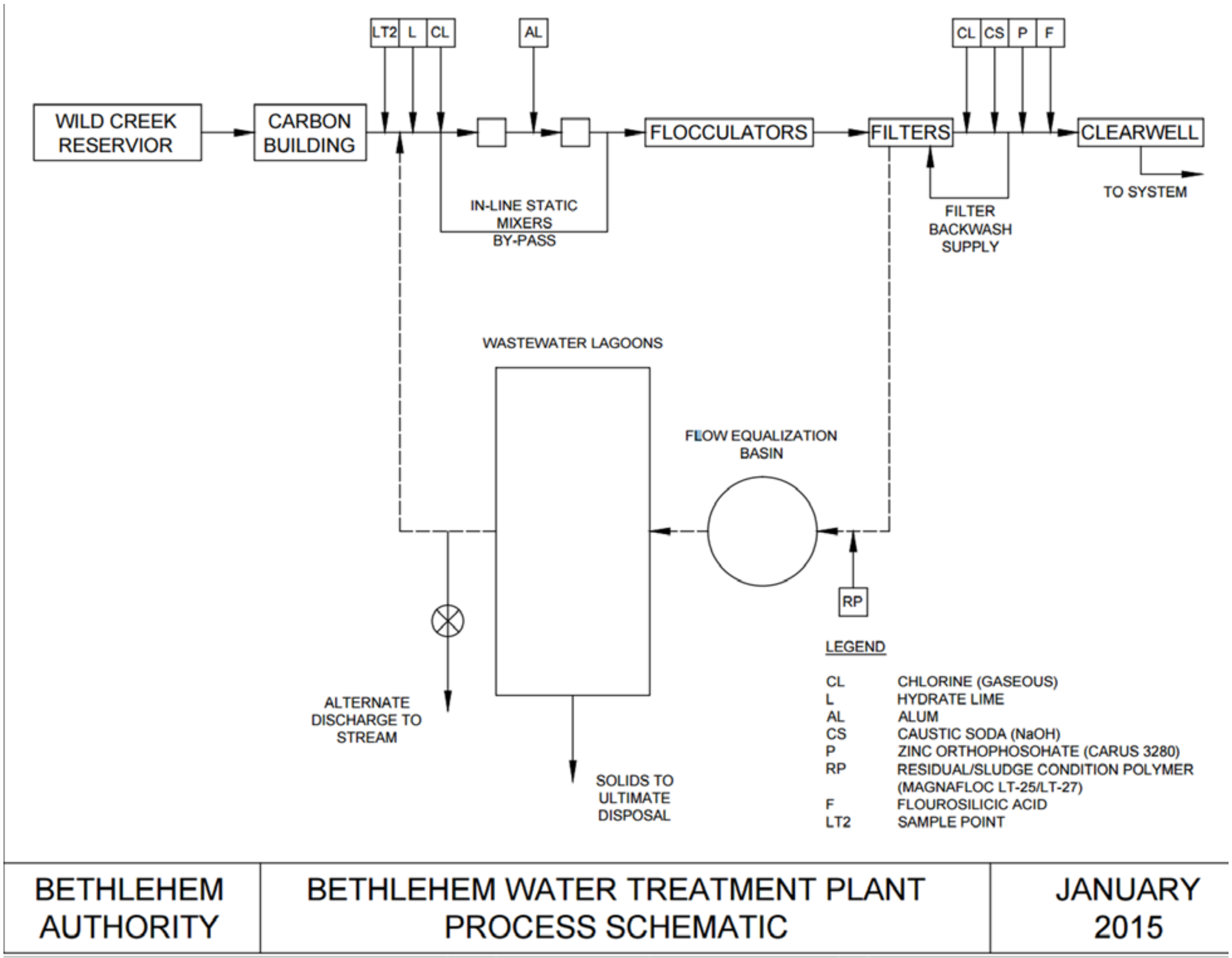


Figure 7: Bethlehem Water Treatment Plant Process Schematic

Water then flows to ten large filters made up of anthracite, gravel and sand. The filters are cleared every 3 days by back pumping water up through the filter in order to collect adsorbed pollutants. This dirty water collected from the filters is deposited in two outdoor lagoons. Water is only deposited in one lagoon at a time, alternating every 6 months. These lagoons are used to settle contaminant particles; the cleaner water at the surface of the lagoon is then recycled back to the beginning of the plant (Brown 2016a).

As the clearwell can only hold 7.66 million gallons, the plant cannot be shut down for an extended period of time. To keep the plant operational, many redundancies have been built into the system, such as several pumps running in series and generators that provides energy during periods without electricity. The system does not have an associated a wastewater plant or river to handle discharge. While the facility does have a discharge permit for a small stream, limits would easily be violated due to its size, so discharges only occur during an emergency (Brown 2016a).

Chemical Additions

Before the Bethlehem Filtration Plant was created, chemicals were administered in a building just downstream of the Wild Creek Dam. The chemicals added included: gaseous chlorine for disinfection, hydrated lime for pH control, hydrofluosilicic acid for fluoride and sodium zinc hexametaphosphate for corrosion control (Andrews 2016c).

The plant's processes include pre- and post-chemical treatment, flocculation and filtration. The facility is equipped to provide chemical treatment with chlorine, alum, fluoride, zinc orthophosphate, caustic soda, lime, carbon, potassium permanganate and polymer. Lime is used at 0.9 mg/L for pH control, gaseous chlorine at 0.8 mg/L for disinfection, and aluminum sulfate, also known as alum, is used for flocculation (Brown 2016b).

Zinc orthophosphate was chosen because of the Lead and Copper Rule. The Lead and Copper Rule was created by the EPA in order to decrease the amount of lead and copper present in drinking water due to pipe corrosion. If lead concentrations exceed an action level of 15 ppb or copper concentrations exceed an action level of 1.3 ppm in more than 10 percent of customer taps sampled, the system must undertake a number of additional actions to control corrosion. If the action level for lead is exceeded, the system must also inform the public about steps they should take to protect their health and may have to replace lead service lines under their control ("Lead and Copper Rule"). The Bethlehem Filtration Plant obtains the zinc orthophosphate from Carus Corporation with the product name of Carus 3280 (Brown, 2016b).

Additionally, fluoride is added to the water at 0.6 to 0.7 mg/L. Before entering the mains, 1.35 mg/L is added along with caustic soda to readjust the pH. Caustic soda is used at this point instead of lime because lime never dissolves completely and would raise the turbidity of the final product (Andrews & Lowry 2013).

Water quality monitoring of treated water at the water treatment plant consists of continuous turbidity, chlorine residual, and pH analyses. Other water quality sampling and testing is conducted as required by PA DEP Safe Drinking Water Regulations (Andrews & Lowry 2013).

1994: Penn Forest Failure

Following the installation of in-depth monitoring equipment in 1969, there was near constant surveillance of the Penn Forest Dam. Through the 26 year period, from 1969 to 1994, monitoring slowly scaled back even with fluctuations in seepage rates. In 1975, and again in 1983, summary reports were drafted, noting high but steady seepage rates. Toward 1994, monitoring procedures included reading approximately 184 instruments on a biweekly basis, including four seepage weirs and two seepage flumes. 49 instruments were strategically picked as samples to represent water levels, which were regularly graphed and analyzed (Bingham et al. 1996).

In addition, several other actions were taken within and around the Penn Forest Dam. In 1978, a thorough Phase I inspection in accordance with the National Dam Inspection Program was conducted. In 1982, an inverted filter was constructed over a high concentration seepage point at the toe of the dam. A stability analysis was performed on the downslope embankment four years later in 1986. Further inspections of the dam and critical features were conducted on an annual basis through 1969 to 1994 (Bingham et al. 1996).

In July of 1994, while the water level was being maintained at spillway crest, piezometric levels in instruments located in the foundation rock in the sinkhole area began to decline. The decline in pressure was masked for sometime because a drawdown of the reservoir started around the same time. The water level dropped to about an elevation of 995 ft and was at that level for several months (Bingham et al. 1999). In November of 1994, after plotting piezometer readings, as seen in Figure 8, there was an evident drop in seven instruments. Overall, piezometric levels in the foundation rock in the vicinity of the original sinkhole declined approximately 10 to 20 ft in the 5 month interval from July to November. The changes in the piezometric levels were interpreted as an early warning sign of potentially recurring piping (Schweiger et al. 1999). A total of 15 instruments showed suspicious fluctuations in seepage rates. The additional 8 instruments affected included some for which data plots were not initially available and those for which the declines were detectable but substantially smaller in magnitude (Bingham et al. 1996). A review of the seepage records showed that the total measured seepage increased to more than 900 gallons per minute, further indicating that the dam was deteriorating (Schweiger et al. 1999).

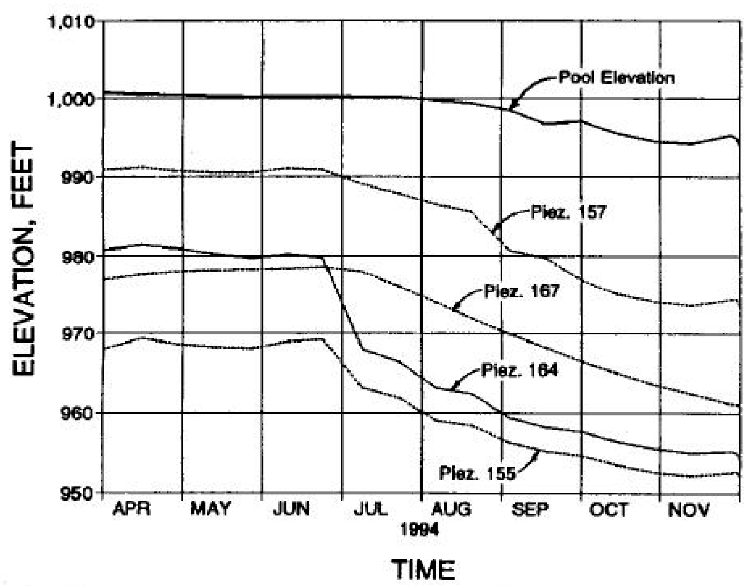


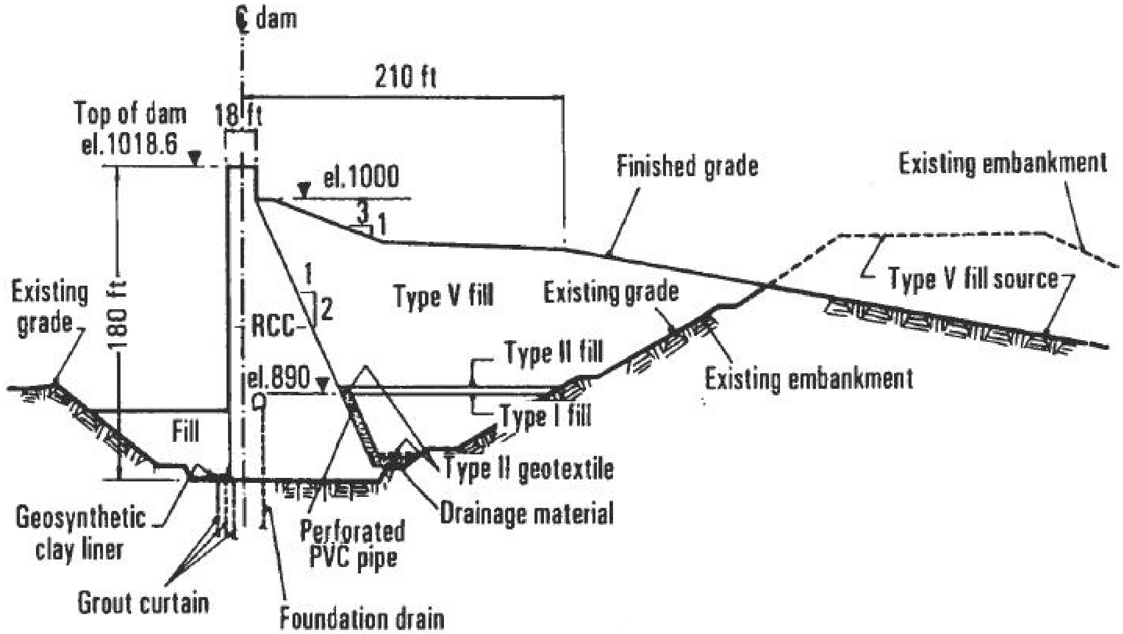
Figure 8: Piezometer Readings 1994 (Bingham et al. 1996)

This drop in piezometer readings was significant enough to warrant precautionary measures. Upon the recommendation of Gannet Fleming, the City of Bethlehem enacted a series of emergency measures, including notifying the Corps of Engineers, the County Emergency

Management personnel, and the State DEP Division of Dam Safety. As a safety precaution the water level was drawn down 2 ft per day to reach an elevation of 985 ft, 15 ft below the spill crest. The water level was then reduced to 950 ft. In addition, piezometer readings were taken daily in the vicinity of original sinkhole area, weir readings were taken, and this data was plotted. Along with the daily localized piezometer readings there are biweekly readings of the rest of the piezometers. Finally, there was mandatory 24-hour visual surveillance of the dam (Schweiger et al. 1999).

After open investigation, it was discovered that the dam contained several fundamental flaws that justified extreme action. A list of seven recommendations were created as standalone solutions or to be used as a combination thereof. The options were as follows: (1) grouting of the embankment and foundation using a variety of techniques; (2) partial removal and reconstruction the dam; (3) installation of an impervious blanket or liner and cutoff at the upstream toe of the dam; (4) installation of a concrete diaphragm wall through the center of the dam and into the foundation; (5) removal of the existing dam and replacement; (6) breach of the existing dam and development of a new water source; (7) lowering of the existing dam and creation of a lower permanent pool, also requiring a supplemental water source (Bingham et al. 1999).

Of these, removal of the existing dam and its replacement with another structure was chosen along with other aspects. A Roller-Compacted Concrete Dam (RCC) gravity dam was constructed approximately 460 ft upstream of the centerline of the existing earth embankment dam. The original cross-section of the proposed RCC dam can be seen in Figure 9. The alignment of the RCC gravity dam was chosen to make full use of the existing spillway and outlet works (Bingham et al. 1996).



Typical Section of RCC Replacement Dam

Figure 9: Cross Section of RCC Replacement Dam (Schwinger et al. 1999)

The gravity dam used only firm rock, in lieu of the original's failures. A conventional grout curtain penetrating through the foundation rock reduced potential for underseepage. A synthetic liner embedded in precast panels on the upstream face of the structure prevented seepage through the structure (Bingham et al. 1996). Drains were provided for the foundation and the dam in order to control and monitor seepage and uplift pressures acting on the base of the dam. Drains also helped to control pore pressures between RCC lift layers. Drains were connected to a drainage gallery located near the base of the structure. Any seepage collected in the drainage gallery is discharged to the existing concrete diversion conduit. The drainage gallery also provides access to the foundation of the dam should any remedial foundation grouting become necessary during the life of the dam (Bingham et al. 1999).

The RCC gravity dam was positioned upstream of the existing embankment in order to replace the embankment while still making use of the existing appurtenances. The existing spillway approach walls were raised 3 ft to increase the spillway capacity to handle the probable maximum flood (PMF). The existing 12 ft diameter concrete diversion conduit was modified to maintain its service as a low-level outlet for the reservoir. Only minor repairs were planned for the existing intake tower (Schweiger et al. 1999).

Since the new gravity dam was located upstream and in the reservoir area of the existing embankment dam, complete drawdown of the existing reservoir was necessary during construction. Facilities for diversion of streamflows for an extended period of time were also required (Bingham et al. 1996).

This project brought the Penn Forest Dam back to its normal operating level. The proposed RCC gravity section relied on the existing embankment for only minimal support, so that in the unlikely case of a minor failure of the embankment section would not have a significant impact on the overall performance of the dam. Additionally, the RCC dam had the most certainty for a long service life with minimal maintenance. Compared to totally replacing the dam, preserving the intake tower and outlet works saved $20 million. While a cofferdam located upstream of the work area permitted streamflow into the reservoir to be released through the 48-inch conduit into Wild Creek with minimal contamination, the draining of the Penn Forest Reservoir compromised 60 percent of the City's water supply storage (Schweiger et al. 1999, Bingham et al. 1999). An accelerated design and construction schedule was imperative to avoid potential water shortages during construction because of the reservoir's integral role in the City's water supply (Bingham et al. 1999).

1994: Construction of Southwest Tank

The 5 million gallon Southwest Tank was constructed in 1994 in the basin of the original 2.7 million open reservoir to serve as its replacement (Andrews & Lowry 2013).

1997: Drought

During the 1997 drought, Bethlehem submitted a permit application to the Delaware River Basin Commission to tap into the Beltzville Lake's feeder stream, Pohopoco Creek (Jordan 1997b, 1997a). The City hoped to draw between 12 to 15 MGD, an amount which would not negatively affect Beltzville Lake, with a new pumping station in order to avoid rationing water (1997b, 1997a). Water could be pumped directly to the water filtration plant, or upstream to replenish the Wild Creek Reservoir. At the time, the Wild Creek Reservoir was receiving 8 MGD from feeder streams while customers were averaging a consumption of 20 MGD. At this rate, the reservoir would be dry by March of 1998 (1997a). This drought was of special concern because the Penn Forest Reservoir was emptied in 1996 to allow for construction. If the drought continued, the City could get by without pumping from Beltzville Lake, but the issue would come to fruition in 1998 to 2000 while the Penn Forest Reservoir refilled. This plan was put forward to pump the water as soon as possible because if the drought became more severe the option would no longer be viable (1997b).

The City planned to use $1 million from the pool of money already borrowed for the reconstruction of the Penn Forest Reservoir. Luckily, the pipeline from Wild Creek Reservoir runs beneath the Pohopoco Creek, so there would have been no major underground pipe work required (Jordan 1997a). Bethlehem Steel also donated four previously used pumps from their inventory for use in this project. The pumps could handle about 14.1 MGD, but the pumps may not have been strong enough to overcome the pressure in the existing water lines due to their age (Jordan 1997b).

Approvals were obtained from the Pennsylvania Department of Environmental Protection (DEP) and the Department of the Army. The PA DEP Water Allocation Permit was issued on February 23, 1998 and expired August 23, 2001, or when the new Penn Forest Reservoir was filled and back in normal service, whichever occurred first. The supplemental emergency source was never constructed (Andrews 2016a).

2001: Supervisory Control and Data Acquisition Improvements

The upgrade of the Technical Division Supervisory Control and Data Acquisition (SCADA) system began in July of 2001, and was completed in May of 2002 (Andrews 2003). The SCADA system is a telemetry network of sensors to collect data on the operation of the system, including pressure transmitters, tank water level monitors, and flow meters in key locations (Andrews & Lowry 2013). The Water Treatment Plant's SCADA system was also upgraded starting in July of 2001 and completed in April of 2002 (Andrews 2003). The previous Iconics Genesis DOS-based HMI software was upgraded to Bristol Babcock's Standard OpenEnterprise package in the server and three workstations. A new server and data concentrator were also added. A new HMI SCADA graphics screen was developed along with the ability to monitor and record individual filter effluent turbidity (Andrews 2016a).

In 2001, the City sought proposals from companies specializing in water audits to track down the 4.8 MGD that had been going missing for perhaps as many as 25 years. The missing one-third of the municipal water was not accounted for in street cleaning, fighting fires, watering the municipal golf course, or water lost through broken pipes. One-third of the system was checked per year for leaks, yet enough had never been found to reduce the unaccounted for water by more than one tenth of a percent. The City speculated that the water could be flowing into the Lehigh River from one of the two unmetered water mains that connects South Bethlehem to the water system. Far more likely, the water was not properly being registered by faulty and old meters because they slow down with age. There were 400 very old, large meters scheduled for replacement from 2001 to 2005. Additionally, 31,000 residential meters could also have been improperly recording flow. South Bethlehem was the suspected location of much of the water loss since many of the conduits there are very old (Ayers 2001).

Over the years, the unaccounted for water amount has decreased due to: continued use of leak detection equipment in the distribution system; the change out of stopped or under-registering water meters; installation of a new calibrated transmitter on the meter chamber venturi of the Water Treatment Plant; better record keeping on unmetered accounted for water; and annual calibration of resale customer meters (Andrews 2016a).

2005: Filtration Plant Improvements

From 2005 to 2008, the Bethlehem Water Filtration Plant filtration system was redesigned for a more uniform application of air and water during the backwash procedure in order to avoid rippling of the filtering media. The 2001 Filter Backwash Recycling Rule, which applies to all public water systems that use conventional or direct filtration of surface water, required these systems to review their backwash water recycling practices to ensure that they do not compromise microbial control. The Rule also required that recycled filter backwash water go through all processes of a system's conventional or direct filtration treatment (US EPA 2015).

The Bethlehem Water Filtration Plant's previous design had a smaller uniformity coefficient of the anthracite, and the garnet sand was clogging the nozzles. The improved design allows for further penetration of the media and a longer period between backwash, due to the deeper bed of media with a high coefficient of uniformity. The new design also has a leopold underdrain. The filters went through a design and pilot testing in order to develop a filter that would work well with the quality of the water supply. Because the Bethlehem facility is a direct filtration plant, the filters needed to be designed to handle an increased turbidity load when required. The old media was removed and the underdrain system replaced. The air wash piping was also redirected into the new underdrains providing uniform air distribution over the filter bed (Brown 2016-B)

The filter wash program was also changed. Originally a sequential wash program that provided a separate air wash then water wash was used. The new program gave two options when washing a filter -- the sequential wash program remained and a concurrent wash program was added. The concurrent program combines the air and water wash, which helps to clean the filter faster. (Brown 2016-B)

The upgrade also included the addition of the backwash water tank located behind the plant. This tank provides gravity feed water to the filters during the wash and holds approximately 650,000 gallons of water, the quantity required for four to five filters washes per day if needed. The tank is filled once per day using a pump located inside the main building. The pump pulls water out of the 72 in pipe prior to the water leaving the main building before it goes into the clearwell storage. The original design utilized a backwash pump to wash the filter. The main difference is that the old pump sends the water directly to the filter that is being washed (Brown 2016).

2008: Sale of Land

The Bethlehem Authority sold 522 acres of the land owned in the Wild Creek Watershed to the Wildlands Conservancy of Emmaus. Though the land parcel was next to the Pocono Raceway, the Bethlehem Authority turned down the raceway's bid because they believed that the Conservancy would be the best steward for the land. The Conservancy agreed to pay $1.65 million for the land parcel, less than the appraised value of $1.925 million. The Bethlehem Authority also placed a deed restriction on the parcel to prevent future development, which was not reflected in the appraised price. The Conservancy also expressed interest in purchasing the remaining 9,000 acres owned by the Bethlehem Authority at market value and allowing the Bethlehem Authority to retain all water rights (Zychal 2008).

2011: Working Woodlands

In 2011, the Bethlehem Authority placed 22,000 acres of their watershed property under a conservation easement for 60 years in partnership with the Nature Conservancy's Working Woodlands Program (Repasch 2011). The Bethlehem Authority agreed to practice sustainable forestry on their property as a part of entering the program, permitting "environmental cuts" that promote forest regeneration (SourcewaterPA, Radzievich 2015). Working Woodlands provided the Bethlehem Authority with an analysis of their property in a Forest Management Plan, access to Forest Stewardship Council (FSC) forest management certification, and carbon markets (SourcewaterPA). The FSC certification provides a third-party assessment of a landowner's forest management practices to ensure the sustainability of the forest and associated water quality, wildlife, and recreation. The Bethlehem Authority was having difficulty marketing their timber, but the certification increases the value of their forest products as buyers are willing to pay a premium for certified products (DCNR 2011, Repasch 2011). The Bethlehem Authority is also now able to participate in a carbon credit program, in which Blue Source, LLC markets the carbon sequestered by these certified sustainable forest management practices, also known as greenhouse gas emission reduction benefits (ERBs). The Bethlehem Authority receives 70 percent of the net proceeds from the sale of ERBs, and the profit goes towards forest preservation (Repasch 2011, DCNR 2011). It has been estimated that the property sequesters approximately 20,000 to 25,000 tons of carbon per year (Repasch 2011).

The Working Woodlands Program enhances the Bethlehem Authority's ability to preserve the quality of the watershed and continue to supply high quality drinking water, while also providing access to a modest revenue source (DCNR 2011).

2012: Improvements to the 12 Million Gallon Reservoir

In 2012, the liner and cover of the 12 million gallon reservoir were replaced (Andrews & Lowry 2013).

2015: PennEast Pipeline Potential Impacts

There is no redundancy or alternate system to replace the 33 MGD transmission capacity through the Wild Creek facilities should they be compromised by the proposed PennEast Pipeline during its construction, operation or in the case of a catastrophic accident. As of 2015, the natural gas pipeline path crossed the Bethlehem Authority property in Carbon County just west of the reservoirs. In Penn Forest Township, the proposed path transversed the headwaters and cross Wild Creek, which is tributary to Penn Forest Reservoir. In Towamensing Township, the proposed path passed 2,000 ft southwest of the toe of Wild Creek Dam, then aligned in close proximity and parallel with the water transmission line from Wild Creek Reservoir to the City of Bethlehem, there the proposed path crossed the water transmission line (Bethlehem Authority 2015). By 2016, the path had not changed significantly. Adjustments have been made to align the pipeline with Lovett Road to avoid the forest area west of Wild Creek Reservoir, and use horizontal drilling to go under the water transmission main at Pohopoco Creek (Andrews 2016a).

As long as controls are implemented during construction, risks associated with routine construction remain low for the headwaters, the Wild Creek dam, and the Wire Ridge Tunnel single water transmission supply line. Construction on the steep slopes of Wire Ridge could potentially increase erosion and reduce the limited soil cover over the water transmission pipe. Geotechnical concerns may arise during installation of the pipeline, especially during the potential use of rock blasting. Without strict adherence to erosion and sedimentation controls, runoff pollution, siltation, and construction equipment fuel contamination of the water supply would be possible. While pollutants that are easily settled are of minimal concern, other than their potential role in long term siltation of the reservoirs, soluble and light insoluble pollutants have the potential of passing through the reservoirs and then causing operational problems and contamination of the Bethlehem Water Filtration Plant (Bethlehem Authority 2015).

Of most concern is a potential pipeline failure resulting in a catastrophic explosion blast from the high pressure dry gas, which could send a shockwave through the rock formation. Such a shock wave could damage or breach the Wild Creek earth fill dam resulting in significant environmental impacts, and hazards to both downstream properties and human safety. Since the Penn Forest Reservoir provides a controlled release to supplement the Wild Creek Reservoir instead of a piped connection from the Penn Forest Reservoir to the Wild Creek Reservoir intake tower, damage to the Wild Creek dam would compromise the water supply of both reservoirs.

The potential shockwave could also damage or cause a breach of the rock bore pressure pipe, leaving the Bethlehem Authority with no means of supplying potable drinking water. With many older liquid petroleum pipelines nearby, a catastrophic explosion and shockwave of the natural gas pipeline could cause the other pipelines to rupture, in turn causing environmental impacts to the watershed and water supply due to liquid petroleum leaks (Bethlehem Authority 2015).

The loss or partial loss of Wild Creek Reservoir for an extended period of time would significantly impact the Bethlehem Authority Water Supply. In the case that the City's water source is compromised or incapacitated, the City has emergency interconnection agreements with five adjacent utilities that can provide up to 5.04 MGD. However, this amount would not completely satisfy the needs of its water customers (Bethlehem Authority 2015).

The anticipated 36 in pipeline would also be installed within a proposed 50 ft cleared right-of-way. Beyond the loss of natural habitat, the loss of woodlands within the Bethlehem Authority property reduces annual VCS carbon credits and timber harvesting revenues. Such right-of-ways are also attractive to all-terrain vehicles, causing increased security challenges during and after construction for the protection of the water supply and watershed assets (Bethlehem Authority 2015).

Concluding Summary of the Current System

As of 2016, the current system serves the City of Bethlehem, Fountain Hill Borough, Hanover Township, Salisbury Township, and Upper Saucon Township in Lehigh County; Freemansburg Borough, Allen Township, Bethlehem Township, East Allen Township, Hanover Township, and Lower Saucon Township in Northampton County. The total safe yield of the Wild Creek and Tunkhannock watersheds combined supply is 26.3 MGD (Andrews & Lowry 2013).

Raw water flows through 30 in, 36 in, and 42 in steel and reinforced concrete transmission mains, and through two 48 in mains in mountain tunnels. While most of the system is in parallel, the two tunnels do not have a redundancy. Treated water flows through 30 in reinforced concrete and 48 in steel mains. At Howertown Control Station the transmission splits into Howertown East and Howertown South Transmission Mains. Howertown East, 34 in and 36 in, extends to the 5 million gallon Northeast Tank and then to the 5 million gallon Southeast Tank. Howertown South extends to the Pennsylvania Avenue Control Station, where the 30 in main splits into 20 in and 24 in mains. The 20 in main extends east to serve the Main Service Area, while the 24 in main extends south to the South Side 12 million gallon reservoir. Distribution storage capacity totals 38.16 million gallons. Technical aspects of the system are detailed before in Tables 2, 3, and 4 (Andrews & Lowry 2013).

Table 2: Service Areas of the Water System

Service Level	**Approximate Elevation Range (ft)**	**Approximate Hydraulic Grade Line (ft)**	**Approximate Pressure Range (psi)**
Main Service	210 - 490	530	20 - 140
Howertown South	340 - 440	650	100 - 135
LVIP #3	320 - 390	500	40 - 90
South Side Low	195 - 400	475	30 - 120
South Side High	310 - 660	743	35 - 190
South Mountain High	740 - 920	1020	45 - 120
Saucon Valley	310 - 530	640	45 - 140
Southeast Low	270 - 415	490	30 - 95
Spring Lake Village	500 - 600	720	50 - 95
Weil Street	690	-	60

(Andrews & Lowry 2013)

Table 3: Pumping Stations of the Water System

Pumping Station	**Service Area**	**Components**
5th & William Booster Pumping Station	From the Main Service Area into the South Side High Gradient, the 1 million gallon tank and the 2 million gallon reservoir	Two electric motor driven pumps, and the third pump has an emergency natural gas powered engine
South Side	From the 5 million gallon Southwest Tank into the South Side High Gradient, the 2 million reservoir, and the 1 million tank	Two electric motor driven pumps, while the third pump is driven by a diesel powered engine.
Fire Pumping Station	From the 1 million gallon tank to the South Mountain High service area and the 500,000 gallon tank	Two pumps have dual drive and can be driven by electric motors or gasoline powered engines, while the third pump is driven by electric motor
Frank's Corner	Serves Spring Lake Village gradient in East Allen Township	Two domestic pumps, one fire pump and three hydropneumatic tanks.
Weil Street Booster Station	Boosts pressures the Weil Street gradient in Salisbury Township	Two pumps with variable frequency drives

(Andrew & Lowry 2013)

Table 4: Storage Facilities of the Water System

Storage Facility	**Capacity (million gal)**	**Overflow Elevation (ft)**	**Serves**
Finished Water Reservoir	7.66	655	Main Service Area
5 MG Northeast Tank	5	540	Main Service Area
12 MG Reservoir	12	480	Flows into Southwest Tank
5 MG Southwest Tank	5	478	South Side Low
5 MG Southeast Tank	5	498	Not in Service
2 MG Reservoir	2	748	South Side High, Saucon Valley
1 MG Tank	1	749	South Side High, Saucon Valley
½ MG Tank	0.5	1026	South Mountain High

(Andrews & Lowry 2013)

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