# PROVIDING QUALITY DRINKING WATER IN CARP ROAD COMMUNITY IN WAKE COUNTY, NC

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A technical report submitted to the faculty at the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Master of Science in Environmental Engineering in Public Health in the Environmental Sciences and Engineering Department in the School of Public Health.

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## ABSTRACT

Yang Du: Costs Analysis of Water Service Lines Extension in Wake County, NC
(Under the direction of Dr. Jackie MacDonald Gibson)

North Carolina defines extraterritorial jurisdictions (ETJs) as areas outside but within 1–3 miles of a municipality. Historically, some African American communities were intentionally zoned into ETJs, in order to legally deny them municipal services, and some communities remain in these exclusionary zones. This project focuses on one such community, located in Wake County, NC. Evidence suggests that this community's domestic wells are at risk of microbial contamination. I evaluated the net present costs over 30 years of three options for protecting these households from waterborne contaminants: extending municipal water service, installing point-of-use treatment, and delivering bottled water. Net social benefits were compared to health costs of taking no action. The net social benefits of extending water service, providing point-of-use treatment and delivering bottled water are -$37,559, -$97,322 and -$620,299, respectively. By comparison, the net social benefit of no action is estimated as -$30,114. Although more costly than no action, I recommend extending community water service to the Carp Road Community as a long-term plan and delivering bottled water as a short-term option until the residents have the community water service to ensure the community has access to clean water.

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# Chapter 1: Introduction and Problem Identification

Exclusions of minority citizens from government services and public utilities can cause racial disparities in economic wellbeing, safety, and public health [1]. In this project, I focused on Wake County, NC, where there are various extraterritorial jurisdictions (ETJs) that currently have no access to municipal water service, instead relying on private wells for their potable water. North Carolina defines ETJs as areas outside a town's boundaries that are within one to three miles of those boundaries. Although the municipal government controls land use, permitting, and zoning in ETJs, ETJ residents do not have the right to vote for town officials. Prior research has suggested that in the U.S. South, some ETJs are the legacy of government-sanctioned racial segregation [1]. In the century following the U.S. Civil War, some local governments established town and city boundaries to exclude minority communities, thereby depriving these minority communities (most of them African American) from resources and services, such as public water, sewage, and police and fire protection. This process of racial under bounding carried various economic, political, and social implications, some of which remain to this day. In this project, I will assess one aspect of the social-environmental problems in such underbounded communities by comparing the net benefit of providing municipal water service to the net benefit of testing the well water on a regular basis and treating the existing private well water and to the net benefit of delivering bottled water, using an underbounded community in Wake County, NC, as an example.

## Engineering Problem

At present, some minority communities residing in the ETJs located in Wake County lack access to a community water system and instead obtain their drinking water from backyard wells, which are unmonitored and may be at risk of contamination. This project assesses whether or not it is possible to extend water service lines to the aforementioned ETJs, and if so, determine the net benefit of such extensions.

Septic systems are one highly prevalent potential source of well contamination in ETJs. A survey by Orange County Health Department in North Carolina found that only 21 out of 45 homes participating in the survey complied with guidelines for septic system performance [2]. Failing systems which are close to private wells can increase the risk of exposure to fecal pathogens and chemical contaminants [3].

The homes considered in this project, apart from not having access to water service lines, have no access to public sewage systems, and therefore rely on septic systems, which in turn pose contamination risks. The presence of septic systems that may be leaking has implications not only for health but also for property value. Prior research on ETJs in Alamance County, NC, observed “with failed septic systems and no access to sewers, the properties have little value” [1].

From the perspective of Wake County government, it is important to establish that the minority communities contemplated in the research were found to be located at relatively short distances from areas that are fully served by public water supplies. Therefore, it is viable to provide water services to the minority communities (located in the ETJs) by simply extending existing water service lines. Also, it should be noted that the (estimated) “social rate of return on historic investments in water treatment systems for municipalities exceeded 23 to 1, with a cost per life-year saved of about $500 in 2003 dollars" [4].

## Public Water Service in Wake County

The City of Raleigh and Western Wake Partners are the two largest providers of water and sewer service in Wake County [5]. The majority of public water in Wake County is collected from the Falls Lake Reservoir located in northern Wake County. The E.M. Johnson Water Treatment Plant and Dempsey E. Benton Water Treatment Plant provide most of the water treatment before the water is distributed to homes and businesses in the county. The drinking water must meet the requirements of the U.S. Safe Drinking Water Act when it leaves the treatment plant and also in the water distribution system. In 2006, the City of Raleigh's E.M. Johnson Water Treatment Plant had the ability to produce 48 million gallons of water per day. The municipal water system also provides an underground network of pipes (water distribution system) to deliver drinking water from the treatment plant to homes and businesses. The water systems in Raleigh have approximately 2,500 miles of water distribution lines that provide drinking water to over 450,000 people [5]. In North Carolina, the percentage of population using drinking water from public water services has increased from 62% to 86% from 1950 to 2005 [6]. The remaining residents obtained the water from self-serviced groundwater. It should be noted that North Carolina ranks the fourth in terms of population that use self-serviced groundwater in the U.S. [7], and not all the ETJs in North Carolina are excluded from water services. Though the Division of Water Resource's Aquifer Protection Section has taken the responsibility of monitoring groundwater quality at some locations throughout the state, the collected data is insufficient to cover all well locations in North Carolina [8].

## Area of Focus

For this project analysis, I selected a community located along Carp Road. Figure 1 shows the location of this area (the grey polygon within gold lines). All of the houses in this area are using private well water, indicated with red numbers from 1 to 11 in Figure 1. Table 1 shows basic demographic data for the neighborhood obtained from American FactFinder website by the United States Census Bureau [9].

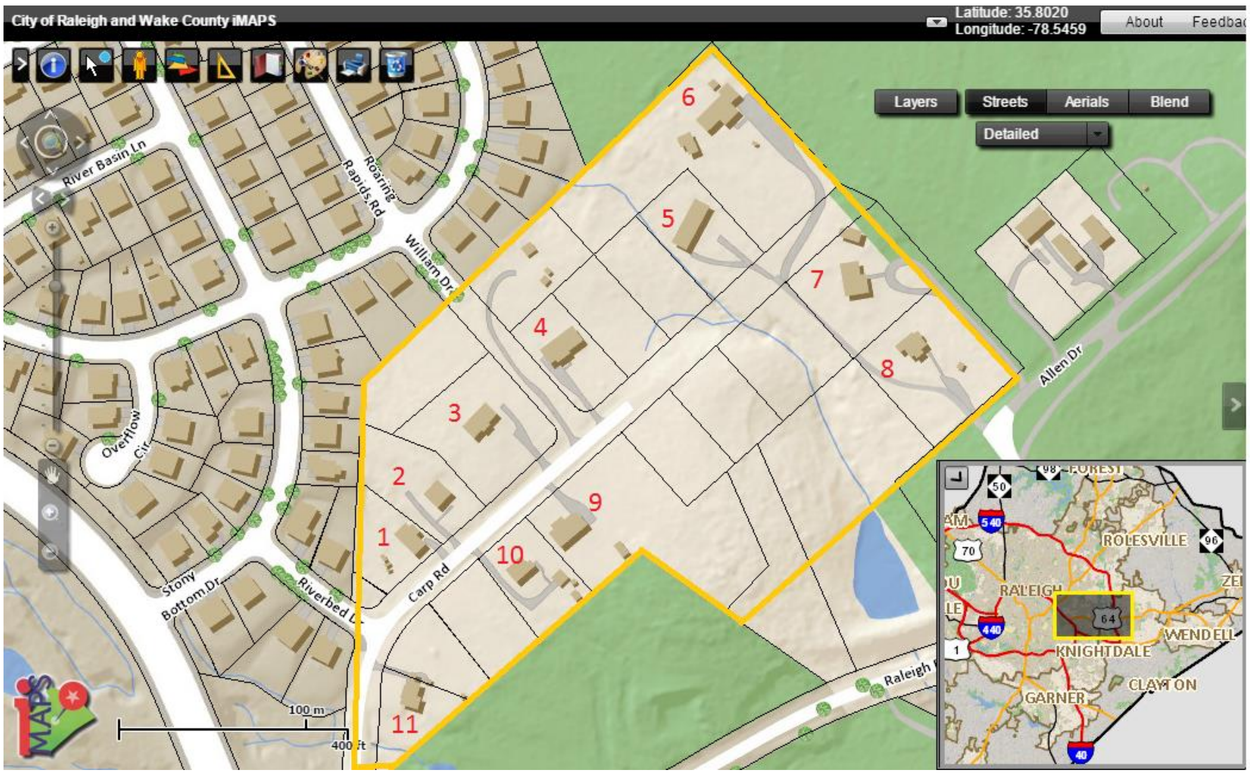



*Figure 1 Area of focus*

*Table 1 Household data of block 1013 in Wake County* [9]

| Race | Total Number of People | Percent |
|---|---|---|
| Total population | 28 | 100 |
| Total households | 11 | 100 |
| White | 4 | 14.3 |
| Black or African American | 20 | 71.4 |
| Asian | 4 | 14.3 |

There are several reasons why this area was selected for this project. Test data for water sampled from one of the wells within the census block (which were collected on Oct.18th, 2014 and Oct. 25th, 2014 ), showed a high concentration of bacteria [10]. A community on the west of this area called Edgewater Community Associates has metered public water service, which indicates that it is feasible to extend the water service lines. The location of Edgewater Community Associates is shown in the yellow-shaded area in Figure 2.

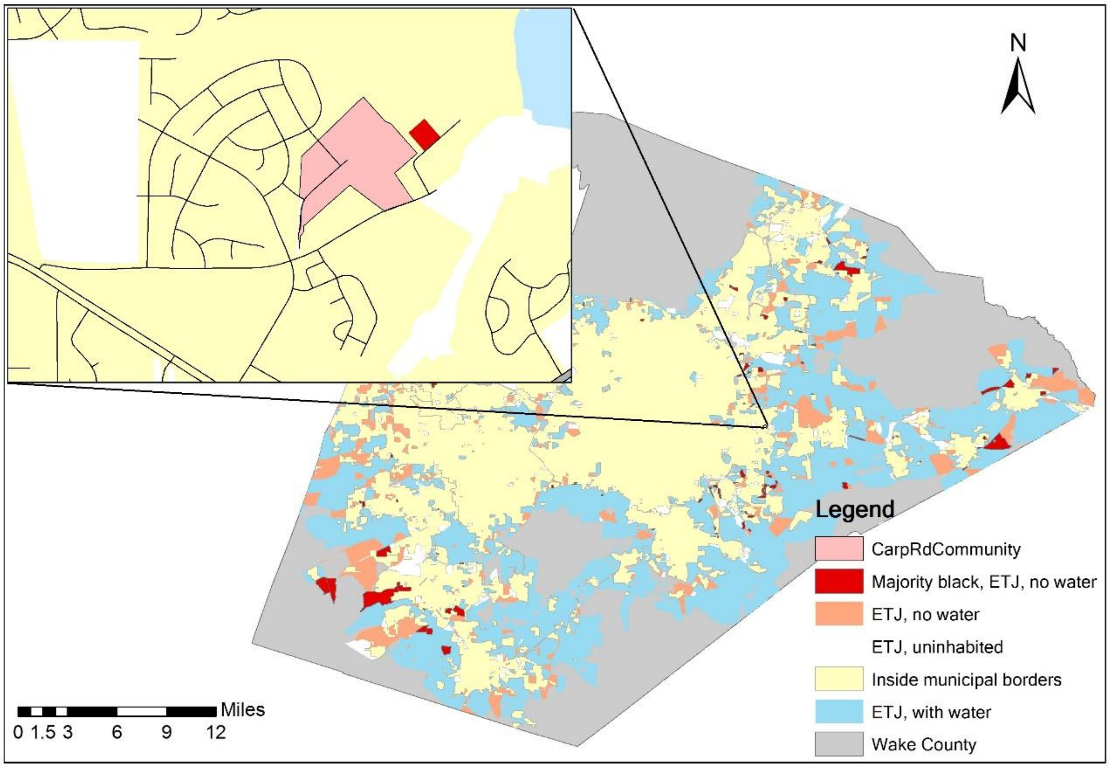



*Figure 2 Area of focus that is close to community water service*

## Objectives

My objectives for the proposed research project is to assess rationally the technical options by which this community can improve its water quality. In order to achieve the objective, I proposed the approaches to the problem are as follows:

1. Design the pipeline extension. I will do this after obtaining information about existing infrastructure in surrounding areas including current sources of water, current water main locations, pumping system, distribution systems (including pipe size, material, water pressure), and soil condition. After that, I will then develop the distribution of the pipelines with appropriate pipe material and size.

2. Develop a cost analysis to determine the viability of extending water service lines for the households without public water service in the selected census block. I will include in the cost analysis components such as pipeline infrastructure, trench and/or rock excavation, installation, operation and management fees, and construction labor fees. The details of the design of the pipeline, cost analysis and comparison with alternatives will be developed in the next section.
3. Determine the cost of installing point-of-use water treatment systems in each home along with regular water quality monitoring at frequencies recommended by the NC Division of Public Health. Costs of this option include the capital costs of the initial installation, costs for periodic replacement of system components, electricity costs to operate the water filters, and water monitoring costs.
4. Determine the costs of delivering bottled water as potable water and using well water for lawn irrigation, toilet flushing, car washing and other non-potable uses over 30 years.
5. Determine the health costs of doing nothing. Health costs consider the risks of acute gastrointestinal illness (AGI) arising from microbial contamination of untreated well water.
6. Calculate the net benefit for each option and compare. Choose the option that has the most net benefit for achieving the overall objective of ensuring public health for this community.

# Chapter 2: Technical Options Analysis

## Approach Overview

My objective for the technical report is to find an option that has the most net benefit value to provide quality drinking water and ensure public health for this community. I analyzed the net benefits associated with the three technical options for improving drinking water in the Carp Road community, in comparison with the net benefit of taking no action.

The three technical options are: (1) extending municipal water pipe lines to the community, (2) testing the well water on a regular basis and installing whole-house filter systems in each house in this community, (3) and delivering bottled water for drinking and cooking water. These three options are compared to the health costs of doing nothing. For the first option, I assume that the Carp Road community would be annexed into the City of Raleigh and therefore would be charged for water service according to within-city prices but also would incur additional municipal property taxes. For the third option, I assume that the residents will continue to use their private well water for bathing, laundry, dishwashing, lawn irrigation, toilet flushing, car washing and other non-potable uses. I estimated the net benefits for each option from two different perspectives: net social benefit and homeowners' net benefit. Costs and benefits considered include the following: capital costs, operation and maintenance costs, property tax and property value costs and benefits, and health costs and benefits. I compared the net cost by computing the net present value (NPV) of net benefits of each option over 30 years using a 3 percent discount rate. I estimated the discount rate based on the July 2015 treasury yield curve rates [11].

## Capital Costs

### Capital Cost for Option 1 (Municipal water service lines extension)

The capital cost of the first option is the cost of all of the materials, labor, and permits required to extend the municipal water lines from the neighboring Edgewater community to the 11 homes in the Carp Road community.

#### *Water Demand Estimation*

To evaluate the construction cost, the first step is to determine if the capacity of the existing system can support the extension to the community.

To evaluate the capacity of the existing water system, I assumed that two connections will be made to the existing water infrastructure, as shown in Figure 3. The blue lines are the existing water service lines. The green dots are the existing fire hydrants. The first connection would be along Roaring Rapids Road, and the second connection would be on Riverbed Drive.

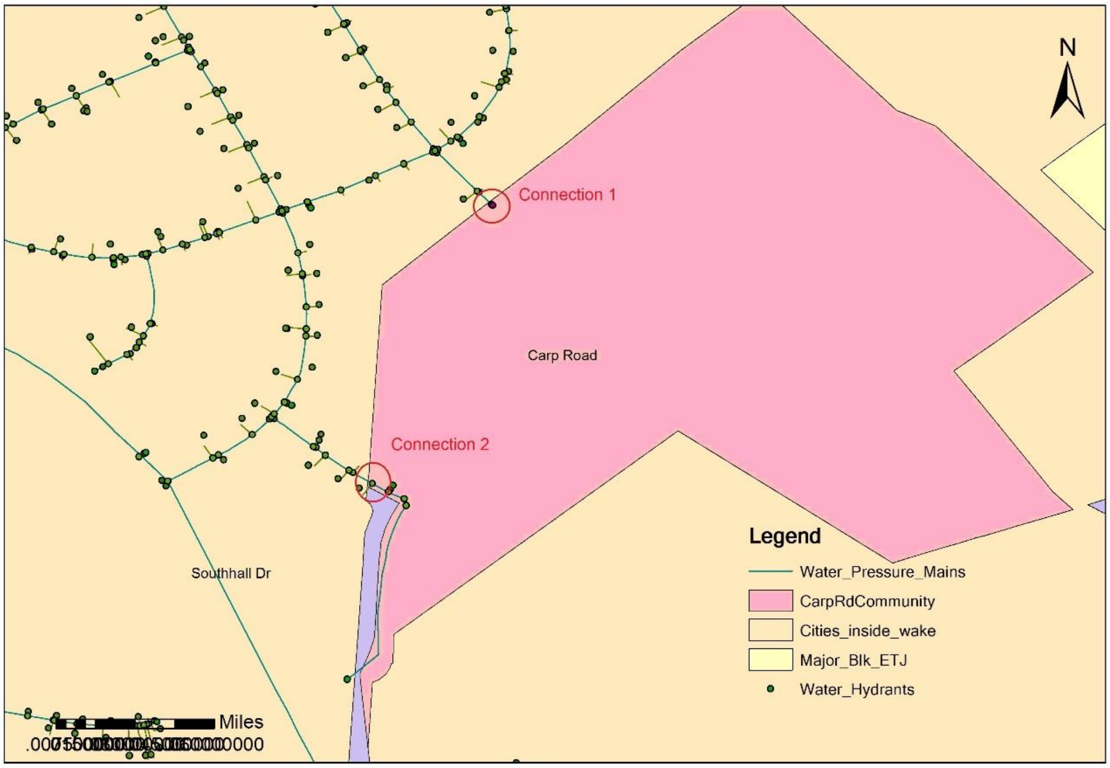



*Figure 3 Designed extended water main connections*

To make sure that the system can actually supply the maximum daily demand as well as the fire flow, the maximum daily demand for the entire community was calculated.

The total community average daily demand (ADD) estimate (96 gpcd * 28 people = 2,688 gallons per day) is based on the assumption that approximately 96 gpcd is required per resident (as indicated in the Raleigh by City of Raleigh Water Resources Assessment Plan for 2013 )[12]. I calculated the maximum daily demand (MDD) by multiplying the ADD by a peaking factor of 1.4 as used by the City of Raleigh for water resources planning projects, giving MDD = 3,763 gallons per day[12]. In order to determine the MDD at each of the two new junction nodes, I assume based on flow directions that five houses (labeled as 4,5,6,7,8) will take water demand from connection 1 and other six houses (labeled as 1,2,3,9,10,11) will take water from connection 2, as shown in Figure 4.

Table 2 shows the estimated average daily demand and maximum daily demand for each node. Todd Davis, the engineer who is updating the City of Raleigh Water Master Plan, confirmed my MDD estimates and then used these estimates along with an existing model of the City of Raleigh water system to determine whether the pressure at each junction node would be adequate to meet the new demand[30]. The results indicate the maximum daily demand pressures of each nodes are 102 psi and 115 psi, meeting the minimum pressure and fire flow requirements for the city of 20 psi, respectively. In addition, Todd's calculation showed a value of actual fire flow of 5,000 gpm at the target community, that 20 psi pressure can be maintained during fire flow water demand of 3,500 gpm.[2] Figure 5 represents the pressures that the two nodes can provide (102 psi and 115 psi), as estimated by Todd Davis using InfoWater (Innovyze, Broomfield, Colorado)[30].

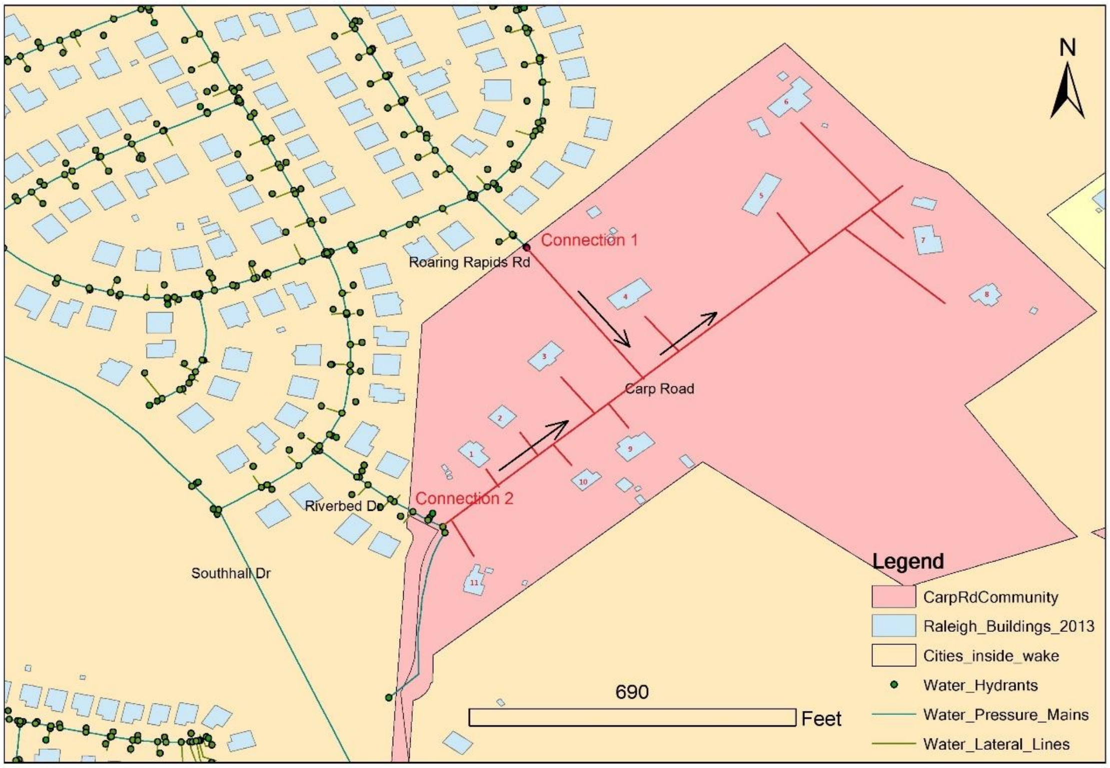



*Figure 4 Flow directions from each node*

*Table 2 Estimated node and community demands*

| Junction | Households served | ADD (GD) | MDD (GD) | MDD pressure (psi) |
|---|---|---|---|---|
| 1 | 5 | 1222 | 1711 | 102 |
| 2 | 6 | 1466 | 2052 | 115 |
| Total | 11 | 2688 | 3763 | |

Carp Rd. Community
Max Day Demand Pressures

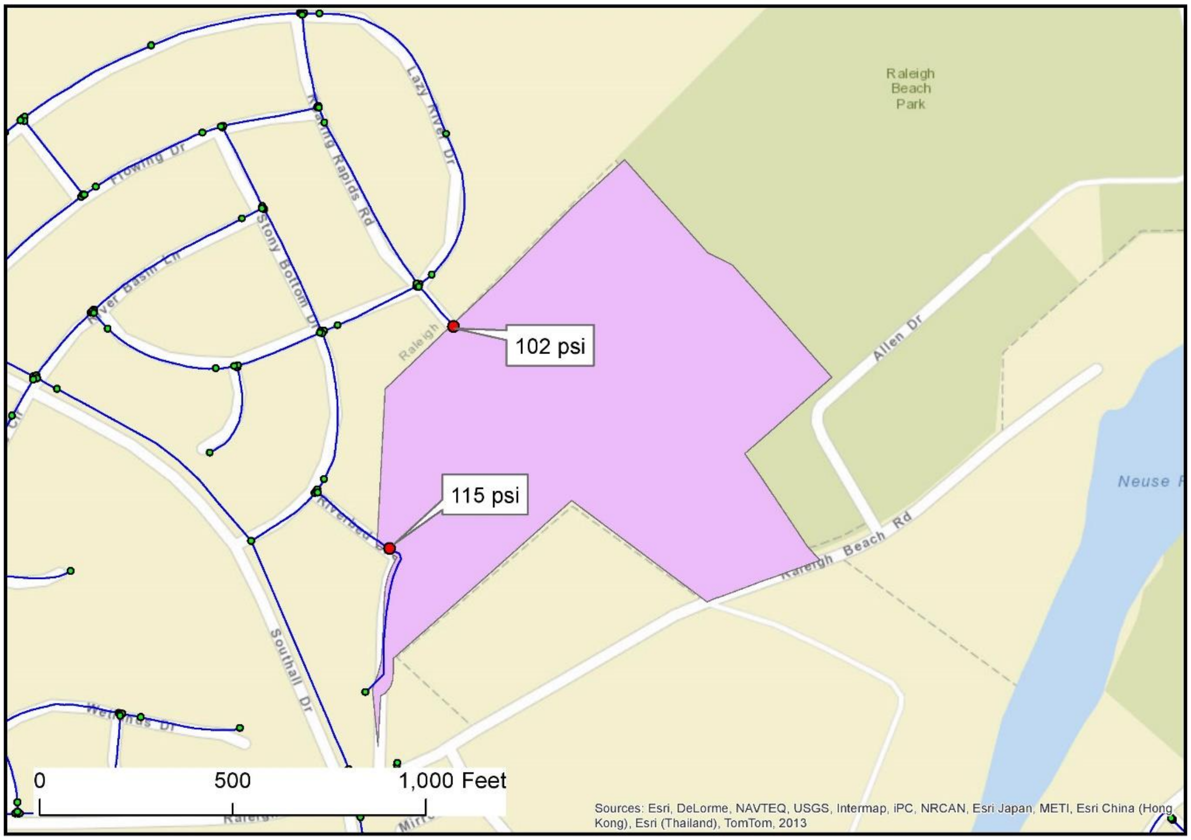



*Figure 5 Estimated pressure of two nodes at max daily demand*

## Water Line Extension Preliminary Design

I devised a preliminary design of the water line extension. The public utility handbook of the City of Raleigh requires that hydrants should be approximately 400 feet from that every intersection as well as every dead end street [2]. Valves also must be placed at every intersection,[2] with a separate valve on each of the three pipes for each T-section. From this preliminary design, I determined that approximately 1050 linear feet of 6-in ductile iron pipe and 3 fire hydrants as well as the other components shown in Table 3 will be needed [2].

In Table 3, the quantity of rock excavated and square yards of asphalt are based on City of Raleigh Standard Water Detail Drawings in Handbook and the length of pipe required.[13]

For example, based on Figure 6 from Handbook, I calculated the total backfill needed as 51 cubic yards, by using Equation 1 as shown below.

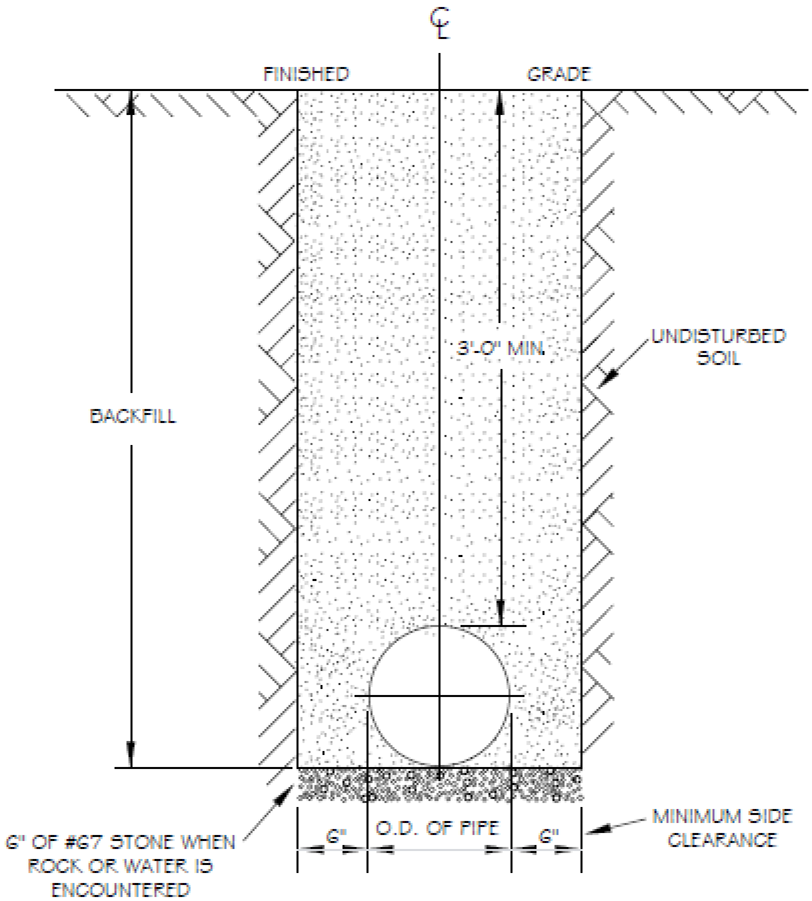



*Figure 6 Trench Dimensions and Backfilling Requirements for Ductile Iron Pipe*

$$Backfill\ needed(CF) = \left\{[(6" \times 2 + O.D.of\ pipe(in)) - \frac{1}{4}\pi O.D.of\ pipe(in)^2] * pipe\ length(ft) * 12\right\}/46656$$

(Equation 1)

One blow-off will be needed based on the topography (Figure 7), since the ground surface elevation is raised from 198 ft to 220 ft and depressed to 202 ft at the end of the proposed main.

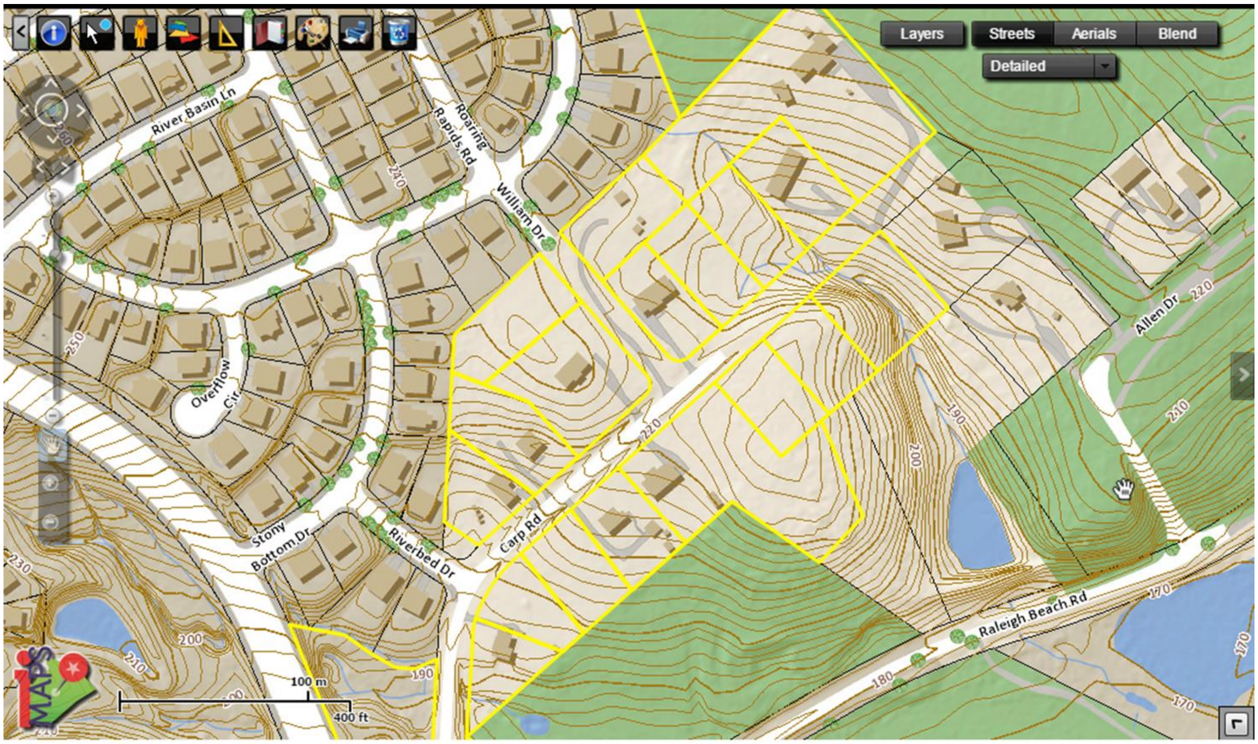



*Figure 7 Topography of Carp Road Community*

The number of connections and water meters is based on the number of households. Quantities of other cost elements (erosion control, water service line restoration, and water testing allowances) are based on bids from four different companies for a previous water main replacement project in the City of Raleigh in 2011, shown in Appendix A and summarized in Table 3. [2]

## Construction Cost Estimate

Table 3 shows the unit costs for each cost element in the previously mentioned four bids for another water main replacement project. I estimated the costs to the City of Raleigh of construction for the Carp Road project at $154,451, based on the average of the highest cost and the lowest cost from the four companies.

*Table 3 Estimated Unit and Total Construction Costs*

| Cost of Construction | | | | Company A | | Company B | | Company C | | Company D | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Item No. | Description | Quantity | Unit | Unit price | Cost | Unit price | Cost | Unit price | Cost | Unit price | Cost |
| 1 | Bonds, Insurance, Mobilization, 2% Max | 1 | LS | $ 3,400 | $ 3,400 | $ 3,600 | $ 3,600 | $ 3,700 | $ 3,700 | $ 4,300 | $ 4,300 |
| 2 | 6" DI Water Main, Class 350 | 1050 | LF | $ 42 | $ 44,100 | $ 50 | $ 52,500 | $ 32 | $ 33,600 | $ 86 | $ 90,300 |
| 3 | Connection to Existing Water Main | 1 | EA | $ 4,300 | $ 4,300 | $ 4,000 | $ 4,000 | $ 3,000 | $ 3,000 | $ 1,217 | $ 1,217 |
| 4 | New Fire Hydrant Assembly | 3 | EA | $ 4,600 | $ 13,800 | $ 4,350 | $ 13,050 | $ 5,000 | $ 15,000 | $ 3,985 | $ 11,955 |
| 5 | Water Meter Assembly to Street R-O-W/Property Line | 11 | EA | $ 515 | $ 5,665 | $ 550 | $ 6,050 | $ 500 | $ 5,500 | $ 479 | $ 5,269 |
| 6 | 6" Gate Valve Assembly | 1 | EA | $ 4,800 | $ 4,800 | $ 1,100 | $ 1,100 | $ 1,000 | $ 1,000 | $ 1,461 | $ 1,461 |
| 7 | Miscellaneous Concrete | 30 | CY | $ 150 | $ 4,500 | $ 140 | $ 4,200 | $ 250 | $ 7,500 | $ 184 | $ 5,520 |
| 8 | Rock Excavation by Mechanical Methods | 51 | CY | $ 15 | $ 760 | $ 35 | $ 1,774 | $ 55 | $ 2,788 | $ 20 | $ 1,014 |
| 9 | Asphalt Roadway Patching | 408 | SY | $ 22 | $ 8,983 | $ 29 | $ 11,638 | $ 44 | $ 17,967 | $ 39 | $ 15,925 |
| 10 | 1 1/2" Asphalt Pavement Overlay | 408 | SY | $ 17 | $ 6,942 | $ 19 | $ 7,554 | $ 15 | $ 6,125 | $ 17 | $ 6,942 |
| 11 | Erosion Control Measures Maintenance and Removal | 1 | LS | $ 1,700 | $ 1,700 | $ 2,500 | $ 2,500 | $ 3,000 | $ 3,000 | $ 5,000 | $ 5,000 |
| 12 | Allowance for Water Servive Line Restoration | 1 | LS | $ 5,000 | $ 5,000 | $ 5,000 | $ 5,000 | $ 5,000 | $ 5,000 | $ 5,000 | $ 5,000 |
| 13 | 3rd Party Testing Allowance | 1 | LS | $ 1,600 | $ 1,600 | $ 1,600 | $ 1,600 | $ 1,600 | $ 1,600 | $ 1,600 | $ 1,600 |
| 14 | Blowoff Assembly | 1 | EA | $ 4,500 | $ 4,500 | $ 5,000 | $ 5,000 | $ 2,263 | $ 2,263 | $ 4,487 | $ 4,487 |
| 15 | 6" Valve | 2 | EA | $ 10,000 | $ 20,000 | $ 7,000 | $ 14,000 | $ 9,000 | $ 18,000 | $ 9,355 | $ 18,710 |
| 16 | 8" x 6" Tapping Sleeve and Valve Assembly | 3 | EA | $ 3,900 | $ 11,700 | $ 4,500 | $ 13,500 | $ 5,000 | $ 15,000 | $ 3,081 | $ 9,243 |
| | | | **Total** | **$** | **141,750** | **$** | **147,066** | **$** | **141,043** | **$** | **187,943** |

In addition to costs to the city, extending the water lines would include costs to homeowners. Households must pay an upfront fee of $2,500 to connect to the service line once the line is installed [14]. There will be a required $50 meter installation fee [14]. A $200 well abandonment fee is also required if the community members are abandoning the well to connect to the line [14]. Assuming homeowners will abandon their wells, the total capital cost to each homeowner is therefore $2,750, and the cost to the community as a whole is $30,250.

## Capital Cost for Option 2 (Testing the well water on a regular basis and installing whole-house filter systems in each house in this community)

The capital cost for option two is the cost of purchasing and installing the whole house filter system. I chose the Aquasana 500,000 gallon Well Water Rhino as the whole house filter system proposed for this report. I chose this filter system because it can be sufficient for a home up to 3500 sq. foot and 3 1/2 baths. The size of each house in this community was obtained from City of Raleigh and Wake County iMaps [15]. The flow rate of the filter system can perform at 7 gallons per minute. The filter system will cost $1,285.70 plus a one-time installation fee of $380 (from the Aquasana website), so the total capital cost is $1,665.70 per home or $18,322.70 for all 11 homes.

## Operation and Maintenance Costs

### Operation and Maintenance Costs for Option 1 (Municipal water service lines extension)

The operation and maintenance cost for extending water service lines is represented by prices charged in the monthly utility bill, which includes a monthly fee based on the amount of water consumed and an administration fee. These fees are paid by the homeowners to the City of Raleigh. Because extending water service lines to these 11 homes would increase the number of service connections in the water utility by only 0.006% (11 new connections/183,000 existing metered connections), the marginal costs to the City of Raleigh is therefore assumed to be zero.

#### *Water Consumption Charge*

The monthly water consumption charges are based on Table 4 from Ordinance No. 2014-317 for the City of Raleigh [16]. The ADD is estimated at 96 gpcd per resident in Raleigh, according to the City of Raleigh 2013 Water Resources Assessment Plan. I calculated the average number of person per household (2.6) by dividing total population in this community (28) by the total households (11). Based on the gpcd per resident and the average number of persons per household, I calculated the ADD per household as 250 gpd, which can be converted as 0.334 hundred cubic feet (CCF) per day per household. Using 10 CCF as the monthly consumption per household and assuming that the Carp Road community is annexed into the City of Raleigh, I estimated the average water consumption charge per household is $31.92/month ($383.04 per year) based on Table 4 [16]. Based on this estimate, with 11 households and an annual discount rate of 3%, I calculated the total water consumption charge at $83,282 over 30 years.

*Table 4 Water consumption charges in City of Raleigh*

| Consumption (CCF/Month) | Unit Rate Per CCF Inside City Limits | Outside City Limits |
|---|---|---|
| Consumption 0 to 4 CCF | $2.28 | $4.56 |
| Consumption 5 to 10 CCF | $3.80 | $7.60 |
| Consumption 11 CCF and greater | $5.07 | $10.14 |

### Water Service Charge

Water service charges are based on Table 5 from City of Raleigh Water Resources Assessment Plan in 2013 [12]. I selected a ¾-inch water meter for each house, resulting in an $8.12 monthly service fee per home, equivalent to an annual per-household cost of $97.44 and a net present value of $21,186 for the whole community over 30 years.

*Table 5 Water monthly service charge from Water Resources Assessment Plan in 2013*

| meter size inches | monthly charges Inside City Limits | Outside City Limits | infrastructure replacement |
|---|---|---|---|
| 5/8 | $5.98 | $11.96 | $1.00 |
| 3/4 | $8.12 | $16.24 | $1.50 |
| 1 | $12.40 | $24.80 | $2.50 |
| 1-1/2 | $23.11 | $46.22 | $5.00 |
| 2 | $35.96 | $71.92 | $8.00 |
| 3 | $70.23 | $140.46 | $16.00 |
| 4 | $108.79 | $217.58 | $25.00 |
| 6 | $215.98 | $431.76 | $50.00 |
| 8 | $344.38 | $688.76 | $80.00 |
| 10 | $494.31 | $988.62 | $115.00 |

### Operation and Maintenance Cost for Option 2 (Testing the well water on a regular basis and installing whole-house filter systems in each house in this community)

Operation and maintenance costs for the second option include testing, operation and maintenance for the filter system.

#### *Testing*

The NC Department of Health and Human Services (NC DHHS) recommends that private well owners test their water annual for bacteria; every two years for heavy metals, nitrates, nitrites, lead, copper and volatile organic compounds; and every five years for pesticides. A summary of well water analysis fees obtained from WakeGov website is presented in Table 6 [17]. For this analysis, I assume that each household will follow the testing frequencies recommended by the DHHS [18].

*Table 6 Well water analysis fees*[1]

| Well Water Analysis: | Cost |
|---|---|
| Bacteriological* | $25 |
| Iron/Sediment* | $20 |
| Inorganic Compounds* | $50 |
| Lead (Elemental)* | $20 |
| Nitrate/Nitrite* | $25 |
| Nitrate Only* | $20 |
| Arsenic (Total)* | $20 |
| Volatile Organic Compounds (VOC)** | $50 |
| Pesticide** | $50 |
| Herbicides** | $50 |
| Radionuclides** | $50 |

[1]*Can be collected by the customer or collected by Wake County Environmental Services for an additional fee of $50.00 per trip; **must be collected by Wake County Environmental Services and require an additional fee of $50.00 per trip* (WakeGOV Water quality)

I estimated the testing costs at $2,848.89 per household over 30 years, resulting a total for the whole community over 30 years of $31,338. Calculation of the testing costs per household per year is shown in Table 7.

*Table 7 Costs of testing for each household over 30 years*

| **Item** | **Test** | **Period** | **Fees** | |
|---|---|---|---|---|
| 1 | Bacteriological | every year | $25 | |
| 2 | Nitrates & Nitrites | every two year | $25 | |
| 3 | Inorganic Compounds | every two year | $50 | |
| 4 | VOCs | every two year | $50 | |
| 5 | Pesticides | every five year | $50 | |
| 6 | Additional fee | every trip | $50 | |
| Year | Item 1 | Item 2,3,4,6 | Item 5,6 | sum |
| 0 | $ 25.00 | $ 175.00 | $ 100.00 | $ 300.00 |
| 1 | $ 24.27 | $ - | $ - | $ 24.27 |
| 2 | $ 23.56 | $ 164.95 | $ - | $ 188.52 |
| 3 | $ 22.88 | $ - | $ - | $ 22.88 |
| 4 | $ 22.21 | $ 155.49 | $ - | $ 177.70 |
| 5 | $ 21.57 | $ - | $ 86.26 | $ 107.83 |
| 6 | $ 20.94 | $ 146.56 | $ - | $ 167.50 |
| 7 | $ 20.33 | $ - | $ - | $ 20.33 |
| 8 | $ 19.74 | $ 138.15 | $ - | $ 157.88 |
| 9 | $ 19.16 | $ - | $ - | $ 19.16 |
| 10 | $ 18.60 | $ 130.22 | $ 74.41 | $ 223.23 |
| 11 | $ 18.06 | $ - | $ - | $ 18.06 |
| 12 | $ 17.53 | $ 122.74 | $ - | $ 140.28 |
| 13 | $ 17.02 | $ - | $ - | $ 17.02 |
| 14 | $ 16.53 | $ 115.70 | $ - | $ 132.22 |
| 15 | $ 16.05 | $ - | $ 64.19 | $ 80.23 |
| 16 | $ 15.58 | $ 109.05 | $ - | $ 124.63 |
| 17 | $ 15.13 | $ - | $ - | $ 15.13 |
| 18 | $ 14.68 | $ 102.79 | $ - | $ 117.48 |
| 19 | $ 14.26 | $ - | $ - | $ 14.26 |
| 20 | $ 13.84 | $ 96.89 | $ 55.37 | $ 166.10 |
| 21 | $ 13.44 | $ - | $ - | $ 13.44 |
| 22 | $ 13.05 | $ 91.33 | $ - | $ 104.38 |
| 23 | $ 12.67 | $ - | $ - | $ 12.67 |
| 24 | $ 12.30 | $ 86.09 | $ - | $ 98.39 |
| 25 | $ 11.94 | $ - | $ 47.76 | $ 59.70 |
| 26 | $ 11.59 | $ 81.15 | $ - | $ 92.74 |
| 27 | $ 11.25 | $ - | $ - | $ 11.25 |
| 28 | $ 10.93 | $ 76.49 | $ - | $ 87.42 |
| 29 | $ 10.61 | $ - | $ - | $ 10.61 |
| 30 | $ 10.30 | $ 72.10 | $ 41.20 | $ 123.60 |
| sum | $ 515.01 | $ 1,864.69 | $ 469.18 | $ 2,848.89 |

### *Operation and Maintenance for the Filter System*

The maintenance costs for the whole house filter system are from replacement of components, including pre-filter, main tanks, post filter and UV bulb, plus labor fees. The operation cost for the filter system is mainly from the electricity costs, most of which result from the UV bulb.

The manufacturer suggests replacing the Sterilight UV Filter annually[19]. The recommended replacement frequencies for the pre-filter and post filter are every three and nine months, respectively. In addition, the main tank must be replaced every 500,000 gallons of water consumed. Table 9 shows costs of these replacement components. I assumed that every component, except the main tank, can be replaced by the homeowners. I further assumed that the main tank must be replaced by a plumber at a labor cost of $100 (2015 U.S. dollar) per hour for an hour of service each time. In addition, I estimated that there would be an annual cost for electricity of $26.68 per household (from the UV light operation). A summary of these costs for one household is shown in Table 9. The detailed calculation of the maintenance and operation costs for the filter system over 30 years is shown in Appendix B. The total cost of the filter system for the whole community is estimated to be $81,005 over 30 years.

*Table 8 Costs of the whole house filter system for one household*

| | | | | |
|---|---|---|---|---|
| **Capital Cost** | | | | |
| | Model | Period | Cost | |
| Whole house well water filter | EQ-Well-UV | one-time | $ | 1,285.70 |
| Installation | | one-time | $ | 380.00 |
| | | | $ | 1,665.70 |
| **Replacement cartridges** | | | | |
| | Model | Period (assumed) | Cost | |
| Pre-filter | EQ-304-20 | 3 months | $ | 7.49 |
| Main tanks | EQ-Well-R | 5 years | $ | 769.99 |
| Post-filter | PFC.35 | 9 months | $ | 29.95 |
| UV-bulb | AQ-UV-STD-LAMP | 1 year | $ | 100.00 |
| Labor | | per hr | $ | 100.00 |
| | | | | |
| **Annual payment** | | | | |
| | Model | Period | Cost | |
| Electricity | | 1 year | $ | 26.68 |

### Operation and Maintenance Cost for Option 3 (delivering bottled water potable water and using well water for other non-potable uses)

The third option, delivering bottled water, requires the residents to purchase bottled water for drinking and cooking. I recommend the residents in this community keep using their well water for non-potable uses, for example, bathing, laundry, dishwashing, lawn irrigation, toilet flushing and car washing. The prices of bottled water are various in the market. However, in this project, I assumed all the residents in this community will use Crystal Springs water. Crystal Springs will deliver potable water at $7.50/five gallons[20]. I assumed that each person will consume 2 gallon/day for drinking and cooking based on EPA's estimation[21]. Assuming each household has 2.6 persons, each household will consume 5.2 gallons of potable water per day. If every households in this community will use 5-gallon Crystal Springs water as their potable water and use well water for non-potable uses, it will cost each household $59,128 and $650,413 for the whole community over 30 years with a 3 percent annual discount rate.

## Property Value and Property Tax Costs and Benefits

I estimated the expected increase in property value of each home if the census block is annexed to the city limits and provided with water service. A previous study of the effects of municipal water service on property values suggests that property values in the Carp Road community could increase by 5.2 to 10.3 percent if all the residents have access to the community service system[22]. Therefore, I assumed that the value of each home would increase by 7.75% (the average of 5.2% and 10.3%). I obtained the current assessed building value for each house from the Wake County iMAPS website (http://www.wakegov.com/gis/imaps/Pages/default.aspx). Table 9 summarizes current and projected potential future values for the 11 houses.

The homeowners must pay an additional Raleigh property tax at the rate of 0.4038% of the total property value if they are annexed to the city limits [23]. The total increase in property taxes over the 30 years thus is estimated to be $95,491 for the whole community over 30 years with an annual discount rate of 3%.

*Table 9 Change of property value and property tax for the community*

| House # | Current Value | 5.2% Increase | 10.3% Increase | Average Increased Value | Property Tax |
|---|---|---|---|---|---|
| 1 | $ 58,634 | $ 3,049 | $ 6,039 | $ 4,544 | $ 255.11 |
| 2 | $ 84,290 | $ 4,383 | $ 8,682 | $ 6,532 | $ 366.74 |
| 3 | $ 104,214 | $ 5,419 | $ 10,734 | $ 8,077 | $ 453.43 |
| 4 | $ 124,790 | $ 6,489 | $ 12,853 | $ 9,671 | $ 542.95 |
| 5 | $ 119,343 | $ 6,206 | $ 12,292 | $ 9,249 | $ 519.25 |
| 6 | $ 148,100 | $ 7,701 | $ 15,254 | $ 11,478 | $ 644.37 |
| 7 | $ 172,054 | $ 8,947 | $ 17,722 | $ 13,334 | $ 748.60 |
| 8 | $ 55,919 | $ 2,908 | $ 5,760 | $ 4,334 | $ 243.30 |
| 9 | $ 127,948 | $ 6,653 | $ 13,179 | $ 9,916 | $ 556.69 |
| 10 | $ 69,780 | $ 3,629 | $ 7,187 | $ 5,408 | $ 303.61 |
| 11 | $ 54,653 | $ 2,842 | $ 5,629 | $ 4,236 | $ 237.79 |
| **Average** | $ 101,793 | $ 5,293 | $ 10,485 | $ 7,889 | $ 442.90 |
| **Total** | $ 1,119,725 | $ 58,226 | $ 115,332 | $ 86,779 | $ 4,872 |

## Health Costs

On the basis of previous evidence that wells in this community are contaminated with fecal indicator bacteria, I assume that residents in the community are at elevated risk of acute gastrointestinal illness (AGI) if they continue to rely on untreated well water for drinking and cooking. Previous study by Stillo tested private well water quality in ETJs in Wake County found that 65% of the samples tested positive for any of the three indicator bacteria (total coliform, *Escherichia coli*, and *Enterococci*). Two out of three samples from one household in this study area showed very high risk for total coliform concentration, with the upper confidence interval of total coliform exceeded the numerical limit of the test system (2419 MPN). The test results of three indicator bacteria for this household is shown in Table 10.[10] I assume that this excess AGI risk could be avoided if the homes are connected to the disinfected municipal water supply or if they install whole-house filters, which remove microbes. I categorized the cost of health issues into three categories: mild cases, moderate cases and severe cases. Mild cases are self-medicated acute gastrointestinal illness (AGI) related incidents. Moderate cases require a non-emergency visit to a health-care provider, and severe cases require an emergency department (ED) visit.

*Table 10 Sample result from one house in Carp Road Community*[10]

| | Test Date | Total Coliform MPN* | *Escherichia coli* MPN*** | *Enterococci* MPN |
|---|---|---|---|---|
| Sample 1 | 08/22/14 | 8.6 (4.5, 16.8) | 0 | 0 |
| Sample 2 | 10/18/14 | 2420.0 (1439.5, TNTC**) | 150.0 (0.3, 5.6) | 6.3 (2.9, 13.7) |
| Sample 3 | 10/25/14 | 2419.6 (1439.5, TNTC) | 2.0 (0.3, 5.6) | 1.0 (0.0, 3.7) |

* MPN = Most Probable Number; ** TNTC = too numerous to count; *** E.*coli* concentration in drinking water has three categories of risk defined by the World Health Organization: Intermediate risk (1-10 MPN/100mL); high risk (11-100 MPN/100mL); and very high risk (>100 MPN/100mL).[24]

To calculate these health benefits, I used the population intervention model (PIM) approach described in DeFelice et al. [25] and adapted by Stillo [10]. I applied the approach as described in Stillo to estimate benefits to the 28 residents of the Carp Road community. The population intervention model yields an estimate of the percentage of AGI emergency department visits that could be avoided if exposure to microbial contaminants in private well water were eliminated. Based on data from the NC Disease Event Tracking and Epidemiologic Collection Tool as described in DeFelice et al. (2015), the population intervention model estimates that 20.75% of these cases could be avoided if exposure to the risk of microbial contaminants in private wells were eliminated. As described by Stillo, Wake County has reported the annual rate of ED visits for AGI between 1/2007 and 10/2013, as a log-normal distribution[10]. Therefore, for the Carp Road community of 28 residents, the estimated total number of AGI cases avoided through either technical intervention is

Avoided ED visits for AGI = *AF** (R*P)

AF = the attributable fraction of ED visits from AGI cases due to private well water consumption (20.75%)

R = the annual rate of ED visits for AGI in Wake County = LN (2.51E-03,5.16E-04) (NCDENR)

P = the population of residents (28)

I performed the PIM model by using Analytica Free 101 Edition and estimated 0.0146 cases (95% CI: 0.0095-0.022) of AGI ED visits per month (0.1752 per year) could be avoided if all the 28 residents in the study area have the access to community water system.

I used data on the severity of AGI from the paper by Phaedra et al. to categorize these prevented AGI cases into mild, moderate, and severe cases. According to Phaedra, 83.3% of AGI-related incidents would be mild and 10.3% would be moderate.[26] As reported by the CDC, based on a national survey conducted between 1996 and 2003, 6.4 percent of those with AGI visit an ED[27].

The health costs for these different types of AGI incidents are shown in Table 11. I obtained the average cost per person (in 1993 U.S. dollars) with mild and moderate illness from the Corso (1993) study of costs of the *Cryptosporidium* outbreak in Milwaukee and adjusted these estimates to 2015 dollars [26]. These two categories costs of illness include the productivity losses as shown in Table 10. For severe cases, I used estimated emergency department visit costs for from BlueCross/BlueShield as medical costs[28], plus the productivity losses costs of $5,781 ($1,409 in 1993 U.S. dollar) as described in Table 11.

On the basis of the estimated number of AGI cases avoided and the cost information in Table 10, the average averted health cost for each household is $139.67 per year, equivalent to $30,114 over 30 years for the whole community (Table 12).

*Table 11 Average cost per person with mild, moderate, and severe[2]*

| Illness severity | Medical costs ($) | Productivity losses ($) | Total ($) |
|---|---|---|---|
| Mild | 2 | 113 | 116 |
| Moderate | 62 | 413 | 475 |
| Severe | 6,399 | 1,409 | 7,808 |
| Average cost of illness | 79 | 160 | 239 |

[a]Costs in 1993 United States dollars.
[b]Costs may not add up due to rounding.

*Table 12 Average costs with mild, moderate, and severe illness*

| Type of AGI incidents | Averted AGI cases (whole community per year) | Percentage of overall AGI incidents | Cost per person | Annual cost for the community | Total averted costs for the community over 30 years (i*=3%) |
|---|---|---|---|---|---|
| Mild (self-medicated) | 2.280 | 83.30% | $228.94 | $522 | $10,232 |
| Moderate (AGI visits for health care provider) | 0.282 | 10.30% | $937.45 | $264 | $5,181 |
| Severe (AGI ED visits) | 0.175 | 6.40% | $4,280.78 | $750 | $14,700 |
| **Total** | **2.738** | **100%** | | **$1,536** | **$30,114** |

## Costs Summary for Four Options

I categorized the net benefits into two main categories: social net benefit and homeowner net benefit.

For the water main extension technical option, the social costs arise from the costs of construction. The benefits are the increases in property value and the averted health costs. The homeowners' costs include those from water consumption, water service charges, property taxes, and the meter installation and one-time connection fees. The homeowners' benefits include the increased property values and the averted health costs.

For the well water testing and treatment, the homeowners' and social net benefit are the same. The costs arise from filter system installation, filter system operation and maintenance, and water testing. The benefits arise from health cost averted.

For the bottled water delivery option, the social net benefit and the homeowners' net benefit arise from the averted health costs and costs of bottled water.

The only net benefit for the do-nothing is from the health cost.

The next section provides summary estimates of the net benefits for each option.

# Chapter 3: Recommended Solution

## Option 1: Extending municipal water pipe lines to the community

For the first option, extending the water mains to the community, I estimated the net benefits as -$37,559 for net social benefits and -$113,316 for the homeowners' benefits over 30 years, with the annual discount rate of 3%. The social cost comes from costs of construction. The social benefits include increased property value and the averted health costs. The homeowners' costs come from the connection fee, meter installation fee, well abandonment fee, water consumption charges, water service charges and property tax. The homeowners' benefits include an increased property value and the averted health costs. The components for the costs and benefits are shown in Table 13.

*Table 13 Social and homeowner net benefits for the water main extension option (with cost in a negative value and benefit in a positive value)*

| Social net benefits | |
|---|---|
| **Cost of construction** | -$154,451 |
| **Property value increased** | $86,779 |
| **Health costs averted** | $30,114 |
| **Total** | -$37,559 |
| | |
| **Homeowner's net benefits** | |
| **Connection fee** | -$27,500 |
| **Meter installation fee** | -$550.00 |
| **Well abandonment fee*** | -$2,200.00 |
| **Water consumption charge** | -$83,282 |
| **Water service charge** | -$21,186 |
| **Property value increased** | $86,779 |
| **Property tax** | -$95,491 |
| **Health costs averted** | $30,114 |
| **Total** | -$113,316 |

*Assume all the residents in this community are abandoning the well to connect to the line

## Option 2: Testing the well water on a regular basis and installing whole-house filter systems in each house in this community

The costs of the-whole house filter system include the installation costs, operation and maintenance costs, and water testing costs (Table 14). Benefits are those associated with avoided AGI cases. In this case, all costs and benefits are accrued by the homeowners, so the homeowners' and net social benefits are the same, totaling -$97,322.

*Table 14 Net benefits analysis for the point-of-use treatment option (with cost in a negative value and benefit in a positive value)*

| | |
|---|---|
| **Social net benefits** | |
| **Initial filter installation costs** | -$18,323 |
| **Filter operation and maintenance costs** | -$77,775 |
| **Water testing costs** | -$31,338 |
| **Health costs averted** | $30,114 |
| **Total** | **-$97,322** |
| | |
| **Homeowners' net benefits** | |
| **Initial filter installation costs** | -$18,323 |
| **Filter operation and maintenance costs** | -$77,775 |
| **Water testing costs** | -$31,338 |
| **Health costs averted** | $30,114 |
| **Total** | **-$97,322** |

## Option 3: Delivering bottled water

The net social benefits for this option are from the averted health costs and the costs of bottled water. The averted health costs have the same value as the first two options. The net homeowners' benefits are the same as the net social benefits. Table 15 shows the summary of net benefits for this option.

*Table 15 Net benefits analysis for the bottled water option (with cost in a negative value and benefit in a positive value)*

| | |
|---|---|
| **Social net benefits** | |
| **Health costs averted** | $30,114 |
| **Bottled water costs** | -$650,413 |
| **Total** | **-$620,299** |
| | |
| **Homeowners' net benefits** | |
| **Health costs averted** | $30,114 |
| **Bottled water costs** | -$650,413 |
| **Total** | **-$620,299** |

## Option 4: Do nothing

The net benefit for the "do-nothing" option arises exclusively from the AGI-related health costs, totaling -$30,114 for both social and homeowner categories over 30 years.

Table 16 summarizes the social and the homeowner net benefits for the four options.

*Table 16 Net costs for the three options*

| TECHNICAL OPTION | SOCIAL NET BENEFIT | HOMEOWNER NET BENEFIT |
|---|---|---|
| **WATER MAIN EXTENSION** | -$ 37,559 | -$ 113,316 |
| **TESTING AND TREATMENT** | -$ 97,322 | -$ 97,322 |
| **DOING NOTHING** | -$ 30,114 | -$ 30,114 |
| **BOTTLED WATER** | -$ 620,299 | -$ 620,299 |

## Sensitivity Analysis

The net benefit analysis of three options was sensitive to the annual discount rate. Figure 8 and Table 17 present the results of the sensitivity analysis. Importantly, if the discount rate increases to 7%, then the net present value of the testing and treatment options social benefit is still less than that of extending water main option, but difference between them becomes smaller. On the other hand, the opposite effect occurs for homeowner benefit: the water service extension option becomes more beneficial to homeowners than the household-level treatment option when the discount rate increases to 7%.

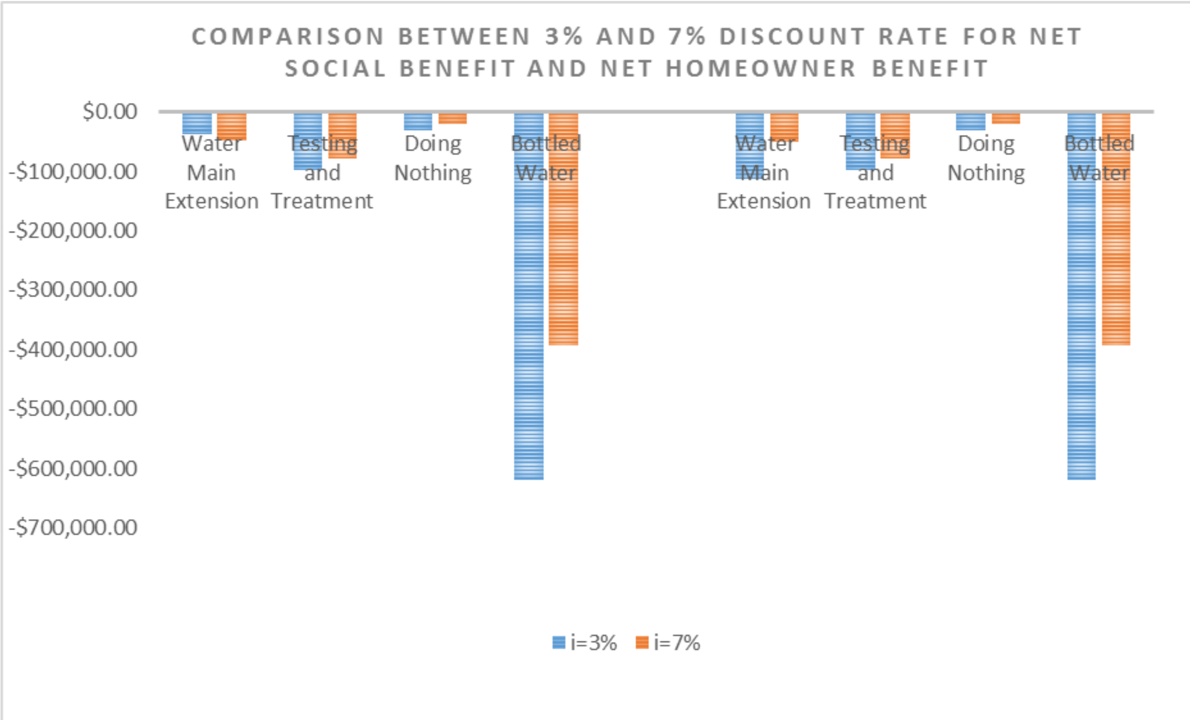



*Figure 8 Comparison between 3% and 7% discount rate for net social benefit and net homeowner benefit*

*Table 17 Comparison between 3% and 7% discount rate for net social benefit and net homeowner benefit*

| ***Technical option*** | **Net Social Cost** | | **Net Homeowner Cost** | |
|---|---|---|---|---|
| | i=3% | i=7% | i=3% | i=7% |
| *Water Main Extension* | -$ 37,559 | -$ 48,607 | -$ 113,316 | -$ 51,063 |
| *Testing and Treatment* | -$ 97,322 | -$ 78,122 | -$ 97,322 | -$ 78,122 |
| *Doing Nothing* | -$ 30,114 | -$ 19,065 | -$ 30,114 | -$ 19,065 |
| *Bottled Water* | -$ 620,299 | -$393,104 | -$ 620,299 | -$393,104 |

## Limitations

There are several limitations to this study. A major limitation is substantial uncertainty in the estimated health benefits. This uncertainty arises from limitations in the PIM method. One limitation is that although the PIM model developed by DeFelice et al. (2015) demonstrated a highly significant association between AGI incidence and microbial water quality in private well water in North Carolina, causation cannot be inferred due to the ecologic nature of the study on which the model was based. That is, exposure and health outcome data used to fit the model were available only at the community level, not at the individual level, as would be needed to support causal inference. In addition, in the PIM model, the AGI risks attributable to private wells may be under-estimated since the model used contaminant data from private wells constructed after 2008 and older wells may have poorer water quality. In addition, the PIM model relied on the use of fecal indicator organism data rather than data on pathogen concentrations, since pathogen data were unavailable. These limitations are explained more fully in DeFelice et al. (2015).

The cost of illness was limited by assuming that the distribution of AGI cases according to severity will be the same as in Phaedra et al. I also assumed the costs of mild and moderate cases will be the same as in the Milwaukee *Cryptosporidium* outbreak, which may also add bias.

Another limitation is that the health benefits of treating the well water may be over-estimated if the water filters fail to perform as designed and/or are not maintained adequately by the homeowners. On the other hand, benefits could be underestimated if exposure to other kinds of contaminants can be avoided by using the whole-house filter system.

The property value may be over-estimated because the averted health costs may be a major factor in the increased property value. The property value increase may partly reflects averted health costs because people know that they can rely on the water service and not get sick.

I calculated the cost based on the 2015 U.S. dollars with an annual discount rate of 3%. One limitation is that costs change, so future users of this work should consider applying current consumer price index as well as current unit prices.

Future research in this area should consider addition of sewer services and solid waste services as part of the water line extension design, as part of cost savings for excavation as well as reduction of the environmental impact of the construction.

## Recommended Solution

I recommended water main extension option because it has the highest net social benefit of the two options for achieving the overall objective of ensuring public health for this community. I eliminated the no-action option because it cannot meet the health protection objective. I decided the recommended solution by assuming that public health protection is the main objective, but there may be other objectives other than net social benefit must be considered in choosing an option, for example, feasibility. In addition to having a lower net social benefit, the well water testing and treatment option was eliminated for feasibility reasons, because the proper maintenance and operation of the filters and routine monitoring may be difficult for homeowners. Homeowners may not adequately maintain the filter systems and therefore the health risks may not be eliminated. The bottled water option is eliminated as a long-term option because the net benefits of this option is very small. The negative values of net benefits for this option represent that it will cost about 6 times as much as the most expensive homeowners' cost among the other three options. I proposed this option as a short-term option to reduce the risk of AGI in this community until the residents have community water services. The solution needs to reflect the values of the homeowners and the City of Raleigh ultimately. They need to agree on an option that provides the most benefits to the community. I suggest using a multi-attribute utility approach as a possible framework for organizing discussion around these and other possible options.

## Chapter 4: Implementation Plan

In this report, I recommended extending water service lines to the community because it would be the most beneficial option and it is the best way to ensure public health for this community. For this option, the costs to the city will include $154,451 construction cost and the costs to the homeowners are $104,000 water bills and $95,491 property tax over 30 years.

Option 1 as outlined in this report would require annexation of the study community into the City of Raleigh. Implementing the annexation process would require the residents to submit a petition to the Department of City Planning to go through approval process. The Annexation Petition Application form can be found on the City of Raleigh website. City staff will submit the application with recommendations to City Council after reviewing the petition. Then the City Council will schedule a hearing on the proposed annexation. Finally, if the annexation is approved by the Council, the petitioners will receive a copy of the ordinance with the start date of the annexation. The application process may take approximately 30 to 40 business days. [29] Once annexation occurs, the utility department would request bids from engineering firms. Those bids would be submitted and one would be chosen. The firm of the accepted bid would conduct a final design and undertake construction, overseen by the City of Raleigh.

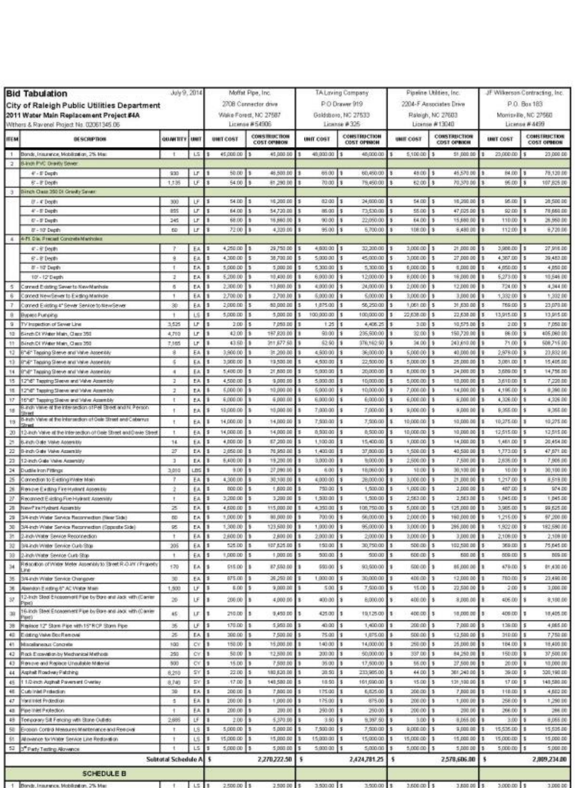
Based on the introduction from Eileen Navarrete, the Construction Projects Administrator from City of Raleigh Public Utilities Department, the contractor or engineer firm should submit the permit for the water project through the City of Raleigh's process, since the City has delegated permitting authority for water projects. Since this project will not disturbing area that is more than one acre of land, Erosion Control Permit is not required.[31]

Long term maintenance has to be considered as well. The public utility department would be responsible for maintaining the constructed water mains; the residents would be responsible for paying water bills as well as maintaining their own plumbing.

There are some potential problems with implementation. The community members may object to be annexed due to higher property taxes, monthly water bills and upfront fees, or only some of the households may want to be annexed. Lack of trust of government may also make them object to the annexation.

Overall, I recommend extending community water service to the Carp Road Community as a long-term plan and delivering bottled water as a short-term option until the residents have the community water services to ensure the public health for the community. I suggest all of the residents in this community to test their well water quality before deciding on the extension. I also suggest the City of Raleigh and the community would organize a discussion to decide a solution that can reflect the values of the homeowners and the city.

Appendix A: City of Raleigh Public Utilities Department 2011 Water Main Replacement Project



**Bid Tabulation** — July 9, 2014

City of Raleigh Public Utilities Department
2011 Water Main Replacement Project #4A
Withers & Ravenel Project No. 02061345.06

| | Moffat Pipe, Inc. | TA Loving Company | Pipeline Utilities, Inc. | JF Wilkerson Contracting, Inc. |
|---|---|---|---|---|
| Address | 2708 Connector drive, Wake Forest, NC 27587 | P.O Drawer 919, Goldsboro, NC 27533 | 2204-F Associates Drive, Raleigh, NC 27603 | P.O. Box 183, Morrisville, NC 27560 |
| License | License #54906 | License # 325 | License #13040 | License # 4499 |
| Subtotal Schedule A | $ 2,270,222.50 | $ 2,424,781.25 | $ 2,578,606.00 | $ 2,809,234.00 |
| Subtotal Schedule C | $ 98,744.50 | $ 121,275.00 | $ 140,645.00 | $ 113,821.00 |
| Subtotal Schedule D | $ 176,660.00 | $ 226,980.00 | $ 217,825.00 | $ 193,254.00 |
| Total Bid Price | $ 2,694,837.00 | $ 2,950,108.75 | $ 3,116,500.00 | $ 3,294,452.00 |

By: ______________________
Daniel Peplinski, P.E.

Corrections made to Bid Proposal by Engineer

Date:

Appendix B: Cost of operation and maintenance for one filter system in 30 years (with cost in a negative value)

| Month | Pre-filter NPV | Main tanks NPV plus labor | Post-filter NPV | UV bulb | Electricity | Sum |
|---|---|---|---|---|---|---|
| 0 | $ - | $ - | $ - | $ - | $ - | $ - |
| 3 | $ -7.43 | $ - | $ - | $ - | $ - | $ -7.43 |
| 6 | $ -7.38 | $ - | $ - | $ - | $ - | $ -7.38 |
| 9 | $ -7.32 | $ - | $ -29.29 | $ - | $ - | $ -36.61 |
| 12 | $ -7.27 | $ - | $ - | $ -29.13 | $ -25.90 | $ -62.30 |
| 15 | $ -7.21 | $ - | $ - | $ - | $ - | $ -7.21 |
| 18 | $ -7.16 | $ - | $ -28.65 | $ - | $ - | $ -35.81 |
| 21 | $ -7.11 | $ - | $ - | $ - | $ - | $ -7.11 |
| 24 | $ -7.05 | $ - | $ - | $ -28.28 | $ -25.15 | $ -60.48 |
| 27 | $ -7.00 | $ - | $ -28.02 | $ - | $ - | $ -35.02 |
| 30 | $ -6.95 | $ - | $ - | $ - | $ - | $ -6.95 |
| 33 | $ -6.90 | $ - | $ - | $ - | $ - | $ -6.90 |
| 36 | $ -6.85 | $ - | $ -27.40 | $ -27.45 | $ -24.42 | $ -86.12 |
| 39 | $ -6.79 | $ - | $ - | $ - | $ - | $ -6.79 |
| 42 | $ -6.74 | $ - | $ - | $ - | $ - | $ -6.74 |
| 45 | $ -6.69 | $ - | $ -26.80 | $ - | $ - | $ -33.49 |
| 48 | $ -6.64 | $ - | $ - | $ -26.65 | $ -23.71 | $ -57.00 |
| 51 | $ -6.59 | $ - | $ - | $ - | $ - | $ -6.59 |
| 54 | $ -6.55 | $ - | $ -26.21 | $ - | $ - | $ -32.75 |
| 57 | $ -6.50 | $ - | $ - | $ - | $ - | $ -6.50 |
| 60 | $ -6.45 | $ -750.46 | $ - | $ -25.88 | $ -23.01 | $ -805.80 |
| 63 | $ -6.40 | $ - | $ -25.63 | $ - | $ - | $ -32.03 |
| 66 | $ -6.35 | $ - | $ - | $ - | $ - | $ -6.35 |
| 69 | $ -6.31 | $ - | $ - | $ - | $ - | $ -6.31 |
| 72 | $ -6.26 | $ - | $ -25.07 | $ -25.12 | $ -22.34 | $ -78.79 |
| 75 | $ -6.21 | $ - | $ - | $ - | $ - | $ -6.21 |
| 78 | $ -6.17 | $ - | $ - | $ - | $ - | $ -6.17 |
| 81 | $ -6.12 | $ - | $ -24.51 | $ - | $ - | $ -30.63 |
| 84 | $ -6.07 | $ - | $ - | $ -24.39 | $ -21.69 | $ -52.16 |
| 87 | $ -6.03 | $ - | $ - | $ - | $ - | $ -6.03 |
| 90 | $ -5.98 | $ - | $ -23.98 | $ - | $ - | $ -29.96 |
| 93 | $ -5.94 | $ - | $ - | $ - | $ - | $ -5.94 |
| 96 | $ -5.90 | $ - | $ - | $ -23.68 | $ -21.06 | $ -50.64 |
| 99 | $ -5.85 | $ - | $ -23.45 | $ - | $ - | $ -29.30 |
| 102 | $ -5.81 | $ - | $ - | $ - | $ - | $ -5.81 |
| 105 | $ -5.76 | $ - | $ - | $ - | $ - | $ -5.76 |
| 108 | $ -5.72 | $ - | $ -22.93 | $ -22.99 | $ -20.45 | $ -72.09 |
| 111 | $ -5.68 | $ - | $ - | $ - | $ - | $ -5.68 |
| 114 | $ -5.64 | $ - | $ - | $ - | $ - | $ -5.64 |
| 117 | $ -5.59 | $ - | $ -22.43 | $ - | $ - | $ -28.02 |
| 120 | $ -5.55 | $ -647.35 | $ - | $ -22.32 | $ -19.85 | $ -695.08 |

Appendix B: Cost of operation and maintenance for one filter system in 30 years (cont'd)

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 123 | $ | -5.51 | $ | - | $ | - | $ | - | $ | - | $ | -5.51 |
| 126 | $ | -5.47 | $ | - | $ | -21.93 | $ | - | $ | - | $ | -27.40 |
| 129 | $ | -5.43 | $ | - | $ | - | $ | - | $ | - | $ | -5.43 |
| 132 | $ | -5.39 | $ | - | $ | - | $ | -21.67 | $ | -19.27 | $ | -46.34 |
| 135 | $ | -5.35 | $ | - | $ | -21.45 | $ | - | $ | - | $ | -26.80 |
| 138 | $ | -5.31 | $ | - | $ | - | $ | - | $ | - | $ | -5.31 |
| 141 | $ | -5.27 | $ | - | $ | - | $ | - | $ | - | $ | -5.27 |
| 144 | $ | -5.23 | $ | - | $ | -20.98 | $ | -21.04 | $ | -18.71 | $ | -65.96 |
| 147 | $ | -5.19 | $ | - | $ | - | $ | - | $ | - | $ | -5.19 |
| 150 | $ | -5.15 | $ | - | $ | - | $ | - | $ | - | $ | -5.15 |
| 153 | $ | -5.11 | $ | - | $ | -20.52 | $ | - | $ | - | $ | -25.63 |
| 156 | $ | -5.08 | $ | - | $ | - | $ | -20.43 | $ | -18.17 | $ | -43.67 |
| 159 | $ | -5.04 | $ | - | $ | - | $ | - | $ | - | $ | -5.04 |
| 162 | $ | -5.00 | $ | - | $ | -20.07 | $ | - | $ | - | $ | -25.07 |
| 165 | $ | -4.96 | $ | - | $ | - | $ | - | $ | - | $ | -4.96 |
| 168 | $ | -4.93 | $ | - | $ | - | $ | -19.83 | $ | -17.64 | $ | -42.40 |
| 171 | $ | -4.89 | $ | - | $ | -19.62 | $ | - | $ | - | $ | -24.51 |
| 174 | $ | -4.85 | $ | - | $ | - | $ | - | $ | - | $ | -4.85 |
| 177 | $ | -4.82 | $ | - | $ | - | $ | - | $ | - | $ | -4.82 |
| 180 | $ | -4.78 | $ | -558.41 | $ | -19.19 | $ | -19.26 | $ | -17.13 | $ | -618.77 |
| 183 | $ | -4.75 | $ | - | $ | - | $ | - | $ | - | $ | -4.75 |
| 186 | $ | -4.71 | $ | - | $ | - | $ | - | $ | - | $ | -4.71 |
| 189 | $ | -4.68 | $ | - | $ | -18.77 | $ | - | $ | - | $ | -23.45 |
| 192 | $ | -4.64 | $ | - | $ | - | $ | -18.70 | $ | -16.63 | $ | -39.96 |
| 195 | $ | -4.61 | $ | - | $ | - | $ | - | $ | - | $ | -4.61 |
| 198 | $ | -4.57 | $ | - | $ | -18.36 | $ | - | $ | - | $ | -22.93 |
| 201 | $ | -4.54 | $ | - | $ | - | $ | - | $ | - | $ | -4.54 |
| 204 | $ | -4.50 | $ | - | $ | - | $ | -18.15 | $ | -16.14 | $ | -38.80 |
| 207 | $ | -4.47 | $ | - | $ | -17.95 | $ | - | $ | - | $ | -22.42 |
| 210 | $ | -4.44 | $ | - | $ | - | $ | - | $ | - | $ | -4.44 |
| 213 | $ | -4.40 | $ | - | $ | - | $ | - | $ | - | $ | -4.40 |
| 216 | $ | -4.37 | $ | - | $ | -17.56 | $ | -17.62 | $ | -15.67 | $ | -55.22 |
| 219 | $ | -4.34 | $ | - | $ | - | $ | - | $ | - | $ | -4.34 |
| 222 | $ | -4.31 | $ | - | $ | - | $ | - | $ | - | $ | -4.31 |
| 225 | $ | -4.28 | $ | - | $ | -17.17 | $ | - | $ | - | $ | -21.45 |
| 228 | $ | -4.24 | $ | - | $ | - | $ | -17.11 | $ | -15.22 | $ | -36.57 |
| 231 | $ | -4.21 | $ | - | $ | - | $ | - | $ | - | $ | -4.21 |
| 234 | $ | -4.18 | $ | - | $ | -16.79 | $ | - | $ | - | $ | -20.97 |
| 237 | $ | -4.15 | $ | - | $ | - | $ | - | $ | - | $ | -4.15 |
| 240 | $ | -4.12 | $ | -481.69 | $ | - | $ | -16.61 | $ | -14.77 | $ | -517.19 |

Appendix B: Cost of operation and maintenance for one filter system in 30 years (Cont'd)

| | | | | | | |
|---|---|---|---|---|---|---|
| 243 | $ -4.09 | $ - | $ -16.42 | $ - | $ - | $ -20.51 |
| 246 | $ -4.06 | $ - | $ - | $ - | $ - | $ -4.06 |
| 249 | $ -4.03 | $ - | $ - | $ - | $ - | $ -4.03 |
| 252 | $ -4.00 | $ - | $ -16.06 | $ -16.13 | $ -14.34 | $ -50.53 |
| 255 | $ -3.97 | $ - | $ - | $ - | $ - | $ -3.97 |
| 258 | $ -3.94 | $ - | $ - | $ - | $ - | $ -3.94 |
| 261 | $ -3.91 | $ - | $ -15.71 | $ - | $ - | $ -19.62 |
| 264 | $ -3.88 | $ - | $ - | $ -15.66 | $ -13.92 | $ -33.46 |
| 267 | $ -3.85 | $ - | $ - | $ - | $ - | $ -3.85 |
| 270 | $ -3.82 | $ - | $ -15.36 | $ - | $ - | $ -19.19 |
| 273 | $ -3.79 | $ - | $ - | $ - | $ - | $ -3.79 |
| 276 | $ -3.77 | $ - | $ - | $ -15.20 | $ -13.52 | $ -32.48 |
| 279 | $ -3.74 | $ - | $ -15.03 | $ - | $ - | $ -18.76 |
| 282 | $ -3.71 | $ - | $ - | $ - | $ - | $ -3.71 |
| 285 | $ -3.68 | $ - | $ - | $ - | $ - | $ -3.68 |
| 288 | $ -3.65 | $ - | $ -14.70 | $ -14.76 | $ -13.12 | $ -46.23 |
| 291 | $ -3.63 | $ - | $ - | $ - | $ - | $ -3.63 |
| 294 | $ -3.60 | $ - | $ - | $ - | $ - | $ -3.60 |
| 297 | $ -3.57 | $ - | $ -14.37 | $ - | $ - | $ -17.95 |
| 300 | $ -3.55 | $ -415.51 | $ - | $ -14.33 | $ -12.74 | $ -446.13 |
| 303 | $ -3.52 | $ - | $ - | $ - | $ - | $ -3.52 |
| 306 | $ -3.49 | $ - | $ -14.06 | $ - | $ - | $ -17.55 |
| 309 | $ -3.47 | $ - | $ - | $ - | $ - | $ -3.47 |
| 312 | $ -3.44 | $ - | $ - | $ -13.91 | $ -12.37 | $ -29.72 |
| 315 | $ -3.42 | $ - | $ -13.75 | $ - | $ - | $ -17.16 |
| 318 | $ -3.39 | $ - | $ - | $ - | $ - | $ -3.39 |
| 321 | $ -3.37 | $ - | $ - | $ - | $ - | $ -3.37 |
| 324 | $ -3.34 | $ - | $ -13.44 | $ -13.51 | $ -12.01 | $ -42.30 |
| 327 | $ -3.32 | $ - | $ - | $ - | $ - | $ -3.32 |
| 330 | $ -3.29 | $ - | $ - | $ - | $ - | $ -3.29 |
| 333 | $ -3.27 | $ - | $ -13.15 | $ - | $ - | $ -16.41 |
| 336 | $ -3.24 | $ - | $ - | $ -13.11 | $ -11.66 | $ -28.02 |
| 339 | $ -3.22 | $ - | $ - | $ - | $ - | $ -3.22 |
| 342 | $ -3.19 | $ - | $ -12.86 | $ - | $ - | $ -16.05 |
| 345 | $ -3.17 | $ - | $ - | $ - | $ - | $ -3.17 |
| 348 | $ -3.15 | $ - | $ - | $ -12.73 | $ -11.32 | $ -27.20 |
| 351 | $ -3.12 | $ - | $ -12.58 | $ - | $ - | $ -15.70 |
| 354 | $ -3.10 | $ - | $ - | $ - | $ - | $ -3.10 |
| 357 | $ -3.08 | $ - | $ - | $ - | $ - | $ -3.08 |
| 360 | $ -3.05 | $ -358.42 | $ -12.30 | $ -12.36 | $ -10.99 | $ -397.13 |
| | | | | | **Total O&M** | $ -5,698.39 |
| | | | | | **Capital Cost** | $ -1,665.70 |
| | | | | | **Total** | $ -7,364.09 |

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