Improving Drinking Water Quality in a Wake County, North Carolina, Neighborhood

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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 the Department of Environmental Sciences and Engineering in the Gillings School of Global Public Health.

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ABSTRACT

Yuyun Liang: Improving Drinking Water Quality in a Wake County, North Carolina, Neighborhood
(Under the direction of Jackie MacDonald Gibson)

Multiple African American communities on the outskirts of municipalities in Wake County, North Carolina, lack access to community water supplies. Instead, these communities use private well water. However, prior evidence suggests these communities are at risk of exposure to well water contamination. In this report, I analyze four options for ensuring drinking water quality in one such community, located on Pheiffer Drive. The options are bottled water delivery; water filtration and routine water testing; well maintenance and repair, along with routine disinfection and water testing; and connection to a neighboring municipal water system. I compare the options on the basis of costs, health risks, and ease of operation and maintenance for homeowners. Other than no action, connecting to the municipal water service is the lowest-cost option. In order to protect residents from the health risks associated with drinking water contamination, I recommend the homes connect to the municipal water system.
ACKNOWLEDGEMENTS

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<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>Annual Cost</td>
</tr>
<tr>
<td>AGI</td>
<td>Acute Gastrointestinal Illness</td>
</tr>
<tr>
<td>AWR</td>
<td>American Water Resources</td>
</tr>
<tr>
<td>CIM</td>
<td>Causal Inference Model</td>
</tr>
<tr>
<td>CIP</td>
<td>Capital Improvement Program</td>
</tr>
<tr>
<td>CWS</td>
<td>Community Water System</td>
</tr>
<tr>
<td>ED</td>
<td>Emergency Department</td>
</tr>
<tr>
<td>EPA</td>
<td>U.S. Environmental Protection Agency</td>
</tr>
<tr>
<td>ETJ</td>
<td>Extra-Territory Jurisdiction</td>
</tr>
<tr>
<td>MCL</td>
<td>Maximum Contaminant Level</td>
</tr>
<tr>
<td>NC</td>
<td>North Carolina</td>
</tr>
<tr>
<td>PIM</td>
<td>Population Intervention Model</td>
</tr>
<tr>
<td>PV</td>
<td>Present Value</td>
</tr>
</tbody>
</table>
CHAPTER I: INTRODUCTION

Background

Prior researchers have found that some African American communities on the outskirts of cities and towns across North Carolina lack community water supply service\(^1,2\).

In North Carolina, cities exercise powers of planning and development in areas known as extra-territorial jurisdictions (ETJs) that extend up to three miles beyond the city boundaries. During the era of legally sanctioned racial segregation, some African American neighborhoods were encompassed within ETJs instead of within the city boundaries, a phenomenon that has been called racial underbounding\(^2\). As a consequence, these minority communities lack access to community water supply and sanitation service.

MacDonald Gibson \textit{et al.} reported that access to water service was significantly lower in African American neighborhoods than in other ETJ neighborhoods in Wake County, NC\(^3\); specifically, the odds of lacking access to water service increased by about 3.8\% with every 10\% increase in the African American population proportion in a U.S. Census block. Figure 1 shows census blocks in Wake County ETJs by racial composition and water service access. As the figure illustrates, although adjacent to or even enclosed by communities with full access to community water supply service, some African American and other communities lack basic municipal water service. Instead, these communities depend on private well water. However, most households in these communities do not disinfect their well water. As a result, these communities may be exposed to waterborne pathogens and higher health risks\(^4\). Between 2001
and 2002, 23 out of 25 (92.0%) of reported waterborne-disease outbreaks in the United States were associated with untreated groundwater or groundwater treatment deficiencies. Furthermore, Stillo reported that 65% of the 57 private wells serving African American neighborhoods in the ETJs of Wake County tested positive for at least one indicator of microbiological contamination.

**Target Community**

In this report, I evaluate options for protecting drinking water safety in one of the Wake County ETJ African American communities identified as lacking municipal water service. Given Stillo’s findings regarding well water microbiological contamination in similar Wake County neighborhoods, the households in this community could face an elevated risk of exposure to microbial contaminants in their drinking water, thereby placing them as risk for acute gastrointestinal illness (AGI). The Pheiffer Drive community’s location is shown in red in Figure 1. At present, all the households in this community depend on private well water as the sole source of their drinking water, while the neighboring community is served by the City of Raleigh public water service system (Figure 2). The target community is relatively small, containing only 4 households (Figure 3) and 7 individuals (per the 2010 U.S. Census), 5 of whom are over 50 years old and all of whom are African American (Table 1).
Figure 1. Wake County, ETJ Census Blocks Without Community Water Service

Figure 2. Pheiffer Drive Community Location and Nearby Public Water Supply System
Figure 3. Locations of Houses in the Pheiffer Drive Community

Table 1. Pheiffer Drive Community Census Information

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Count (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Houses</td>
<td>4</td>
</tr>
<tr>
<td>Occupied</td>
<td>4 (100)</td>
</tr>
<tr>
<td>Owner-occupied</td>
<td>4 (100)</td>
</tr>
<tr>
<td>Individuals</td>
<td>7</td>
</tr>
<tr>
<td>African American</td>
<td>7 (100)</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>3 (43)</td>
</tr>
<tr>
<td>Female</td>
<td>4 (57)</td>
</tr>
<tr>
<td>Age (years)</td>
<td></td>
</tr>
<tr>
<td>Under 18</td>
<td>1 (14)</td>
</tr>
<tr>
<td>20-24</td>
<td>0 (0)</td>
</tr>
<tr>
<td>25-34</td>
<td>0 (0)</td>
</tr>
<tr>
<td>35-49</td>
<td>1 (14)</td>
</tr>
<tr>
<td>50-64</td>
<td>2 (29)</td>
</tr>
<tr>
<td>65 and over</td>
<td>3 (43)</td>
</tr>
</tbody>
</table>

* NC-Wake County-Census Tract 530.08-Block 2002
Technical Options Considered

In this report, I consider the costs and health benefits of the following five options for managing drinking water quality in the target community:

Option 1: No action (maintain the current situation in the target community)

Option 2: Bottled water delivery – each household will purchase delivered, purified bottled water from Crystal Springs water company.

Option 3: Household well water filter system installation plus well water testing - each household will install a 500,000 gallon well water Rhino Whole House Filter System (produced by Aquasana). To ensure the filter is performing as intended, each household will also conduct annual tap water quality tests (bacteria, nitrates, lead) as recommended by the Wake County Human Services Laboratory.

Option 4: Well maintenance and repair plus well water disinfection plus well water testing - each household will be provided with well maintenance and repair services by American Water Resources (AWR), including well piping, valves and switches, pressure tanks, etc. In addition, each household will conduct annual well water disinfection using calcium hypochlorite. The Wake County Human Services Laboratory will also conduct an annual well water quality test for each household.

Option 5: Connection to neighboring municipal water service system - each household will connect to the City of Raleigh municipal water service system. Under this option, water testing is not needed, since the Raleigh water service system conducts regular water testing and provides reliable water quality monitoring.

For each option, I consider the costs and health benefits from two perspectives: those for community residents and those for the City of Raleigh. Community costs and benefits balance the out-of-pocket costs to individual households against the health benefits gained through reduced exposure to contaminated water. Costs and benefits for the City of Raleigh (option 5) balance the cost to city taxpayers of extending municipal water lines against the additional service fee and tax revenue income gained by incorporating the Pheiffer Drive community.
CHAPTER II: ANALYSIS OF TECHNICAL OPTIONS

Overall Analysis Framework

As mentioned in the previous chapter, to increase drinking water quality and decrease the health risk triggered by well water contamination for the target community, I considered the following technical options on a cost-benefit basis:

Option 1: No action
Option 2: Bottled water delivery
Option 3: Household well water filter system installation plus well water testing
Option 4: Well maintenance and repair plus well water disinfection plus well water testing
Option 5: Connection to City of Raleigh municipal water service system

Overall Cost Assumptions

I used a 30-year time frame for this analysis and computed the total costs and benefits for each option over that time frame based on net present values. Thirty years is a typical planning horizon for municipal utility projects due to typical debt repayment periods, infrastructure lifetimes, and decreases over time in the present values.

Per the guidelines in Office of Management and Budget Circular A-94, which establishes the principles of cost-benefit analysis for federal agencies, I used a discount rate of 3% as a measure of the social rate of time preference, and adopted this discount rate over the
30-year time frame to avoid time-inconsistency problems. As per Circular A-94, I used a discount rate of 7% for the sensitivity analysis.7

I assumed that there were no contamination risks over the 30-year time frame (e.g., chemical contamination) other than microbiological well water contamination, such as that reported by Stillo.6 Consequently, for this report, I defined health costs as those due to acute gastrointestinal illness (AGI) triggered by well water microbial contamination. I adopted a population intervention model (PIM) previously published by DeFelice9 to evaluate the AGI health risks. I assumed that the illness costs would be eliminated when any of the technical options was taken.

Cost Elements of Each Option

The cost elements of each option are listed in Table 2. For well water testing, since most target community residents are elderly and may lack the skills necessary to collect well water samples, I assumed that there would be additional costs in the form of environmental service fees and well water analysis fees charged by Wake County Environmental Services.

Table 2. Cost Elements of Each Option

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
<th>Cost elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No action</td>
<td>Health costs</td>
</tr>
<tr>
<td>2</td>
<td>Bottled water delivery</td>
<td>Purchase costs</td>
</tr>
<tr>
<td>3</td>
<td>Household well water filter system installation plus well water tests</td>
<td>Capital costs, labor fees, electricity fees, environmental service fees, well water analysis fees</td>
</tr>
<tr>
<td>4</td>
<td>Well maintenance and repair plus well water disinfection plus well water tests</td>
<td>American Water Resources (AWR) service fees, disinfectant (calcium hypochlorite) costs, environmental service fees, well water analysis fees</td>
</tr>
<tr>
<td>5</td>
<td>Connection to City of Raleigh water service system</td>
<td>Borne by target community residents: one-time connection application fee, water consumption charges, water service charges</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Borne by Raleigh City government: pipeline construction fees</td>
</tr>
</tbody>
</table>
Viewpoints Considered

I assessed the costs and benefits for each option from the following two viewpoints to determine potential alternative views of the most desirable solution for improving drinking water quality:

- Residents in the target community – I assumed that the residents would prefer an improvement in drinking water quality at a reasonable and acceptable price and that technical options must be easy for homeowners to operate (necessary to guarantee option effectiveness).

- Raleigh city government – I assumed that the City would be willing to pay for the costs of water service line extensions if the public health improvements and increases in city income generated through water service charges were sufficiently high.

Option 1

The only cost associated with option 1 (no action) is that associated with AGI resulting from microbiological contamination of the well water in the community. To evaluate the AGI health risk, I applied a causal inference model (CIM), which incorporated a PIM fitted to monthly county-level health outcome and water quality data, then applied the model using the Analytica software package to estimate the average number of community monthly AGI emergency department (ED) visits avoided (Table 3). The PIM was previously developed by DeFelice, and the development of the CIM from this PIM is described in Stillo. In brief, the CIM calculates the number of avoided AGI ED visits using the following equation:

\[
\text{avoided AGI ED visits} = AF \times R \times P = 0.208 \times 2.51 \times 10^{-3} \times 7 = 3.65 \times 10^{-3}
\]

Table 3. Causal Inference Model Inputs and Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Modeling Method (mean, standard deviation)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>AF</td>
<td>Attributable Fraction</td>
<td>Normal (0.208, 9.17×10^{-3})</td>
<td>Stillo</td>
</tr>
</tbody>
</table>
Rate of ED Visits for AGI in Wake County, NC (Monthly Visits Per Person) Lognormal (2.51×10^{-3}, 5.16×10^{-4}) DeFelice^9  
Population (Persons) 7 2010 NC census U.S. Census

Table 3 describes the terms in this equation and their sources.

After running the model, I obtained a value of 3.65×10^{-3} (95% confidence interval: 2.54×10^{-3}– 5.03×10^{-3}) for the average number of community monthly AGI ED avoided visits, and 4.38×10^{-2} for the average number of community annual AGI ED avoided visits if all risk of microbial contamination were eliminated.

The number of ED visits estimated from CIM model in this report overlooks the potentially large number of AGI cases that will not result in ED visits. To estimate the total number of AGI cases potentially attributable to microbial contamination in the community and their level of severity, I applied Phaedra S.C et al.’s 1993 figures^10 for the percentage of infected individuals with different severity (mild, moderate, severe) to the annual average number of avoided community AGI ED visits. To obtain the costs of these AGI cases, I used illness costs reported in Phaedra. The illness costs are composed of medical costs and productivity losses (Table 4).

**Table 4. Cases Category and Costs^10**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>Did not seek physician or ED care</td>
<td>88</td>
<td>2</td>
<td>113</td>
<td>115</td>
<td>173</td>
</tr>
<tr>
<td>Moderate</td>
<td>Had at least one physician or ED visit but was not hospitalized</td>
<td>11</td>
<td>6</td>
<td>416</td>
<td>422</td>
<td>633</td>
</tr>
<tr>
<td>Severe</td>
<td>Hospitalized at least once during the illness outbreak period</td>
<td>1</td>
<td>6,399</td>
<td>1,409</td>
<td>7,808</td>
<td>11,712</td>
</tr>
</tbody>
</table>
On the basis of U.S. dollar implicit price deflators for gross domestic product, I multiplied the 1993 health costs by 1.5 to adjust for inflation and obtained the 2014 health cost values\(^\text{11}\) (Table 4).

I assumed the avoided ED visits estimated in this report are infected persons with severe diarrhea. With the same percentage of infected individuals with different severity, I estimated the number of infected person with moderate AGI per year is 0.482 and the number of infected person with mild AGI per year is 3.86.

\[
\text{infected persons with moderate AGI per year} = \frac{0.0438}{1.00\%} \times 11.00\% = 0.482
\]

\[
\text{infected persons with mild AGI per year} = \frac{0.0438}{1.00\%} \times 88.00\% = 3.86
\]

As shown in Table 5 and the following calculations, I estimated the present value of the community total health costs at $29,080:

\[
\text{total costs for infected persons with mild AGI per year} = 3.86 \times 172.5 = 665
\]

\[
\text{total costs for infected persons with moderate AGI per year} = 0.482 \times 633.0 = 305
\]

\[
\text{total cost for infected persons with severe AGI per year} = 0.0438 \times 11,712.0 = 513
\]

\[
PV \text{ of the community total illness costs} = A \left( \frac{(1+i)^N - 1}{i(1+i)^N} \right)
\]

\[
= (665 + 305 + 513) \times \left( \frac{(1 + 0.03)^{30} - 1}{0.03 \times (1 + 0.03)^{30}} \right) = 29,080
\]

<table>
<thead>
<tr>
<th>Illness severity</th>
<th>Infected persons (/yr)</th>
<th>Total cost per case ($)</th>
<th>Total annual cost for community($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>Percent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mild</td>
<td>3.86</td>
<td>173</td>
<td>666</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>Severe</td>
<td>Total annual cost</td>
</tr>
<tr>
<td>----------------</td>
<td>----------</td>
<td>--------</td>
<td>-------------------</td>
</tr>
<tr>
<td></td>
<td>0.482</td>
<td>0.0438</td>
<td>1,484</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>1</td>
<td>633</td>
</tr>
<tr>
<td></td>
<td>305</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Option 2**

Under option 2, each household will purchase a delivery service for bottled purified water from Crystal Springs.

I assumed that the individual consumption of bottled water in the target community is 3.5 L/day on the basis of the Dietary Reference Intakes for water established by the Food and Nutrition Board in 2004\textsuperscript{12}. The average number of persons in each household is 1.75. Thus, each household will purchase 5 bottles of 5 gallons per bottle of purified water every half month at the price of $7.49 per bottle\textsuperscript{13}. Additionally, Crystal Springs will charge $2.41 as a variable energy surcharge for each delivery\textsuperscript{13}. The present value of the total costs of bottled water delivery by Crystal Springs over 30 years is $18,916 per household.

\[\text{water needed} = 3.5 \text{L/day} \times 1.75 \times 15 \text{day} \times 0.264 \text{gallons/liter}\]

\[= 25 \text{gallons per half month}\]

\[
P V = A \left( \frac{(1 + i)^N - 1}{i(1 + i)^N} \right) = ($7.49 \times 5 + $2.41) \times \left( \frac{(1 + \frac{0.03}{12 \times 2})^{30 \times 12 \times 2} - 1}{\frac{0.03}{12 \times 2} \times (1 + \frac{0.03}{12 \times 2})^{30 \times 12 \times 2}} \right)\]

\[= $18,916\]

**Option 3**

Under option 3, each household will install a 500,000 gallon well water Rhino Whole House Filter System (produced by Aquasana) (Figure 4) and will conduct the annual well water
quality tests recommended by the Wake County Human Services Laboratory to guarantee the filter system performance.

![Whole House Filter System 500,000 Gallon Well Water Rhino](image)

**Figure 4. Whole House Filter System 500,000 Gallon Well Water Rhino**

**Household Well Water Filter System Installation and Operation**

- **Upfront Costs**

  The upfront capital cost of the whole filter system is $1,286\textsuperscript{14}. The filter system requires installation by skilled labor. I assumed that the Mr. Rooter Plumbing Company would provide the labor with the original installation fees of $380\textsuperscript{15}. Thus, the total upfront costs of the filter system is $1,666.

  \[
  \text{total upfront costs} = 1,285.70 + 380 = 1,666
  \]

- **Operation and Maintenance Costs**

  This system is composed of a sediment pre-filter, main tanks (copper-zinc and mineral stone, activated carbon filter), sub-micron post-filter and UV-disinfection system (Table 6).
Table 6. Components of Household Filter System

<table>
<thead>
<tr>
<th>Component</th>
<th>Function</th>
<th>Consumption period</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediment pre-filter</td>
<td>Catches rust, sediment and silt</td>
<td>0.25</td>
<td>7.49</td>
</tr>
<tr>
<td>Copper-zinc &amp; mineral stone</td>
<td>Reduces chlorine, water soluble heavy metals, and scale and inhibits bacteria and algae growth</td>
<td>5</td>
<td>769.99</td>
</tr>
<tr>
<td>Activated carbon filter</td>
<td>Reduces herbicides, pesticides and other chemical compounds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub-micron post-filter</td>
<td>Reduces any remaining sediment and organic particles down to 0.35 microns</td>
<td>0.75</td>
<td>29.95</td>
</tr>
<tr>
<td>UV-disinfection system (40 W)</td>
<td>Further protects against bacteria and viruses</td>
<td>1</td>
<td>100.00</td>
</tr>
</tbody>
</table>

The consumption period-based schedule of component replacement is recommended to ensure the filter system’s effectiveness. I calculate the costs of components replacement over the period of 30 years as below.

The present value of the costs of the filter system’s component replacements is composed of pre-filter (estimated at $591.08), main tank (estimated at $2,842.67), post-filter (estimated at $784.50), and UV bulb (estimated at $1,960.04) costs.

Pre-filter: \[ PV = A \left( \frac{(1+i)^N - 1}{i(1+i)^N} \right) = 7.49 \times \left( \frac{(1+0.03\times0.25)^{30}-1}{0.03\times0.25\times(1+0.03\times0.25)^{30}} \right) = 591.08 \]

Main tanks: \[ PV = \sum F/(1 + i)^N = \sum_{N=1}^{30/5} \frac{$769.99}{(1 + 0.03)^N} = 2842.67 \]
Post-filter: \[ PV = A \left( \frac{(1+i)^{N-1}}{i(1+i)^N} \right) = 29.95 \times \left( \frac{(1+0.03\times0.75)^{30}-1}{0.03\times0.75\times(1+0.03\times0.75)^{30}} \right) = 784.50 \]

UV bulb: \[ PV = A \left( \frac{(1+i)^{N-1}}{i(1+i)^N} \right) = 100.00 \times \left( \frac{(1+0.03)^{30}-1}{0.03\times(1+0.03)^{30}} \right) = 1,960.04 \]

Summing these component costs estimates yields a total components update cost of $6,178.

\[ PV = 591.08 + 2,842.67 + 784.50 + 1,960.04 = 6,178 \]

I assumed that the Mr. Rooter Plumbing Company would provide the labor for the replacement every 3 months of the component with the fees of $100 per trip\(^{15}\). Thus, I estimate the present value of the labor cost of component replacement at $7,894.

Component replacement fee:

\[ PV = A \left( \frac{(1+i)^N - 1}{i(1+i)^N} \right) = 100 \times \left( \frac{(1+0.03\times0.25)^{30}-1}{0.03\times0.25\times(1+0.03\times0.25)^{30}} \right) = 7,894 \]

The filter system’s power requirement is rated at 40 W. I estimated the electricity fees resulting from the filter system operation based on the charge rates of Duke Energy Carolinas, LLC (Table 7)\(^{16}\).

<table>
<thead>
<tr>
<th>Table 7. Energy Charge Rates of Duke Energy Carolinas, LLC(^{16})</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Summer months</strong></td>
</tr>
<tr>
<td>(June 1 – September 30)</td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>On-peak energy cost per month, per kWh</td>
</tr>
<tr>
<td>Off-peak energy cost per month, per kWh</td>
</tr>
<tr>
<td>On-peak period hours</td>
</tr>
<tr>
<td>Monday - Friday</td>
</tr>
<tr>
<td>Off-peak period hours</td>
</tr>
</tbody>
</table>
I assume that this filter system will be operated 24 hours a day over the period of 30 years.

In a year, there are 260 weekdays and 105 weekend days; excluding the holidays which fall on weekends; the number of days counted as off-peak holidays is 6.

Thus, the number of on-peak period hours for the summer months is 508.

\[
On – Peak\,\, period\,\, hours\,\, for\,\, summer\,\, months\,\, = \, \frac{(260 - 6) \times 4 \times 6}{12} = 508\,\, hours
\]

The number of on-peak period hours for the non-summer months is 1016.

\[
On – Peak\,\, period\,\, hours\,\, for\,\, non – summer\,\, months\,\, = \, \frac{(260 - 6) \times 8 \times 6}{12} = 1016\,\, hours
\]

The number of off-peak period hours for the summer months is 2412.

\[
Off – Peak\,\, period\,\, hours\,\, for\,\, summer\,\, months\,\, = \, \frac{(105 + 6) \times 4 \times 24}{12} + \frac{(260 - 6) \times 4 \times (24 - 6)}{12} = 2412\,\, hours
\]

The number of off-peak period hours for the non-summer months is 4824.

\[
Off – Peak\,\, period\,\, hours\,\, for\,\, non – summer\,\, months\,\, = \, \frac{(105 + 6) \times 8 \times 24}{12} + \frac{(260 - 6) \times 8 \times (24 - 6)}{12} = 4824\,\, hours
\]

The electricity fee for the On-Peak period for the summer months is $2.81.

\[
electricity\,\, fees\,\, in\,\, the\,\, On – Peak\,\, period\,\, for\,\, summer\,\, months\,\, = \, 0.04\,\, kwh \times 508\,\, hours \times 0.138381\$/kwh = 2.81
\]
The electricity fee for the on-peak period for non-summer months is $5.05.

\[
\text{electricity fees in the On – Peak period for non – summer months} \\
= 0.04 \text{ kw} \times 1016 \text{ hours} \times 0.124290$/kwh = $5.05
\]

The electricity fee in the off-peak period for the summer months is $6.27.

\[
\text{electricity fees in the Off – Peak period for summer months} \\
= 0.04 \text{ kw} \times 2412 \text{ hours} \times 0.065013$/kwh = $6.27
\]

The electricity fee in the off-peak period for the non-summer months is $12.54.

\[
\text{electricity fees in the Off – Peak period for non – summer months} \\
= 0.04 \text{ kw} \times 4824 \text{ hours} \times 0.065013 = $12.54
\]

Thus, the annual cost of electricity is $26.68.

\[
\text{annual cost of electricity} = 2.81 + 5.05 + 6.27 + 12.54 = $26.68
\]

The present value of the total electricity fee is $523.

\[
P V = A \left( \frac{(1 + i)^N - 1}{i(1 + i)^N} \right) = 26.68 \times \left( \frac{(1 + 0.03)^{30} - 1}{0.03 \times (1 + 0.03)^{30}} \right) = $523
\]

Summing the total update cost of components, labor cost of replacement and electricity fees yields the total costs of operation and maintenance of $14,595.

\[
\text{total costs of operation and maintenance} = 6,178 + 7,894 + 523 = $14,595
\]

**Well Water Tests**

Wake County Human Services Laboratory recommends annual well water quality tests to ensure the intended performance of the filter system.
• Environmental Service Fees

Since most of residents in this community are elderly and may lack the skills necessary to obtain a water sample, I assume that the well water samples will be collected by Wake County Environmental Services at a fee of $50 for every trip

The present value of the total environmental service fees is $980.

\[
PV = A \left( \frac{(1 + i)^N - 1}{i(1 + i)^N} \right) = 50 \times \left( \frac{(1 + 0.03)^{30} - 1}{0.03 \times (1 + 0.03)^{30}} \right) = 980
\]

• Well Water Analysis Fees

The U.S. Environmental Protection Agency (EPA) recommends that annual well water quality tests include bacteriological, nitrate, lead and chemicals specific to the situation. I assume for the purposes of this report that the sole source of well water contamination in the target community over the 30-year timeframe will be microbiological. I further assume that all contaminants are tested initially and that only bacteriological indicators, nitrate, and lead are tested annually over the 30-year period. The well water analysis fees charged by the Wake County government are listed in Table 8.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacteriological</td>
<td>25.00</td>
</tr>
<tr>
<td>Iron/sediment</td>
<td>20.00</td>
</tr>
<tr>
<td>Inorganic compounds</td>
<td>50.00</td>
</tr>
<tr>
<td>Lead (elemental)</td>
<td>20.00</td>
</tr>
<tr>
<td>Nitrate/nitrite</td>
<td>25.00</td>
</tr>
<tr>
<td>Nitrate only</td>
<td>15.00</td>
</tr>
<tr>
<td>Arsenic (total)</td>
<td>20.00</td>
</tr>
<tr>
<td>Pesticide</td>
<td>50.00</td>
</tr>
<tr>
<td>Item</td>
<td>Cost ($)</td>
</tr>
<tr>
<td>--------------</td>
<td>----------</td>
</tr>
<tr>
<td>Herbicides</td>
<td>50.00</td>
</tr>
<tr>
<td>Radionuclides</td>
<td>50.00</td>
</tr>
</tbody>
</table>

Based on my assumption that all contaminants are tested initially and only the bacteriological, nitrate, and lead tests are repeated annually, the initial well water analysis cost is $265 (excluding the bacteriological, nitrate, and lead tests).

\[
PV = 20 + 50 + 25 + 20 + 50 + 50 + 50 = 265
\]

The present value of costs for bacteriological, nitrate, and lead testing over the period of 30 years is $1,441.

\[
PV = A \left( \frac{(1 + i)^N - 1}{i(1 + i)^N} \right) = (25 + 15 + 20) \times \frac{(1 + 0.03)^{30} - 1}{0.03 \times (1 + 0.03)^{30}} = 1,441
\]

The present value of the total costs for well water analysis is $1,706.03.

\[
PV = 265 + 1,441 = 1,706
\]

**Option 4**

Well maintenance and repair is the third potential option for improving water quality. Regular maintenance and repair could eliminate continuous well water contamination caused by improper well construction and poor well maintenance. Under option 4, American Water Resources will provide each household with well maintenance and repair services, including repair or replacement of well piping, valves and switches, pumps, and pressure tanks. Each household will conduct well water disinfection annually and, as in option 3, will conduct or have conducted for them annual well water quality tests.
Well Maintenance and Repair

- Well Company Service Fees

American Water Resources charges $3,500 per year for well maintenance and repair\(^{19}\). The provided services include repair and replacement for pumps, vertical lines, pitless adapters, well caps, horizontal service lines, electric cables, pressure tanks, other well piping, valves and switches\(^{19}\).

The present value of American Water Resources’ fees for well maintenance and repair is $68,602 per household.

\[
P_V = A \left( \frac{(1 + i)^N - 1}{i(1 + i)^N} \right) = 3,500 \times \left( \frac{(1 + 0.03)^{30} - 1}{0.03 \times (1 + 0.03)^{30}} \right) = 68,602
\]

Well Water Disinfection

Under option 4, each household would use calcium hypochlorite as the well water disinfectant. Well water disinfection should be conducted whenever microbiological contamination appears or after significant flooding\(^{20}\). According to the USGS’s peak flow records for Swift Creek, located approximately 5 miles from the target community, there were 13 peak streamflow appearances from 2000 to 2012\(^{21}\). I therefore assume that well water disinfection is conducted annually.

- Disinfectant Cost

At present, calcium hypochlorite is regarded as the most satisfactory and efficient water disinfectant from a cost perspective\(^{22}\). I further assume that households will use Dry Tec Calcium Hypochlorite Chlorinating Shock, which contains 68% calcium hypochlorite (Table 9)\(^{23}\).
According to the geographic information provided by U.S. Geological Survey (USGS), the well water depth in the City of Raleigh area is around 15 feet\textsuperscript{24}. I assume that the average well diameter in the target community is 6 inches. Thus, 2 tablespoons of dry calcium hypochlorite chemical (68\% hypochlorite) is required for each well water disinfection\textsuperscript{20}.

The present value of the cost of calcium hypochlorite disinfection is $16 per household.

\[
PV = \sum_{N=0}^{30/16} \frac{F}{(1 + i)^N} = \sum_{N=0}^{30/16} \frac{9.74}{(1 + 0.03)^N} = 16
\]

Well Water Tests

Well water tests will be conducted in the same manner and at the same costs as in Option 3.

Option 5

Under this option, each household will connect to the neighboring municipal water service system. Whereas all costs for Options 1-4 are borne by the homeowners, for this option both the homeowners and the City of Raleigh would incur costs.

Costs to Homeowners

Following the guidelines in the Handbook of the City of Raleigh Public Utilities Department\textsuperscript{25}, I selected the 3/4 inch water meter for each household in the target community.

---

Table 9. Calcium Hypochlorite Product Information\textsuperscript{23}

<table>
<thead>
<tr>
<th>Product</th>
<th>Amount</th>
<th>Consumption period</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Tec Calcium Hypochlorite</td>
<td>1 lb</td>
<td>16 years</td>
<td>$9.74</td>
</tr>
<tr>
<td>Chlorinating Shock</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
- Application Fees

According to the July 2015-2016 Development Fee Schedule Comprehensive Guide for Raleigh Development Fee, Raleigh City government will charge $2,238 (one-time per household) as a capital facilities fee for a ¾ inch water service connection\textsuperscript{26}.

- Water Consumption Charges

According to the 2013 City of Raleigh Water Resources Assessment Plan\textsuperscript{27}, Raleigh’s average daily water demand is 96 gallons per capita per day. The residential water consumption charges, which are regulated by Ordinance No. 2014-317 of the City of Raleigh, are listed in Table 10\textsuperscript{28}.

<table>
<thead>
<tr>
<th>Consumption (CCF/Month)</th>
<th>Unit Rate Per CCF ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inside City Limits</td>
<td>Outside City Limits</td>
</tr>
<tr>
<td>0 to 4</td>
<td>2.28</td>
</tr>
<tr>
<td>5 to 10</td>
<td>3.80</td>
</tr>
<tr>
<td>11 and greater</td>
<td>5.07</td>
</tr>
</tbody>
</table>

The total target community population is 7, there are 4 houses, and the average number of people per house is 1.75, resulting in an average household daily water demand of 168 gallons per day, an average household monthly water demand of 6.74 CCF, and monthly household water charges of $19.52. This calculation assumes that the community is annexed into the City of Raleigh and therefore pays the inside-city fees.

\[ \text{household average daily water demand} = 1.75 \times 96 = 168 \text{ gallons per day} \]

\[ \text{household average monthly water demand} = 168 \text{ gallons per day} \times 30 \text{ day} = 6.74 \text{ CCF} \]
household monthly water charges = 4 CCF × $2.28 + (6.74 − 4) CCF × $3.80 = $19.52

Thus, the present value of water consumption total costs is $4,631 per household.

\[ PV = A \left( \frac{(1 + i)^N - 1}{i(1 + i)^N} \right) = 19.52 \times \left( \frac{\left(1 + \frac{0.03}{12}\right)^{30 \times 12} - 1}{\frac{0.03}{12} \times \left(1 + \frac{0.03}{12}\right)^{30 \times 12}} \right) = 4,631 \]

- Water Service Charges

According to Fee Schedule Ordinance No. 2015-419 (Section 8-2005)\textsuperscript{26}, the City of Raleigh charges initial fees of $224 for a ¾ inch water meter. Additionally, the city levies an $8.12 monthly service charge for each ¾ inch water meter inside city limits\textsuperscript{28}. The city requires that water meters be replaced every 15 years\textsuperscript{28} (at a fee of $1.50\textsuperscript{28}) due to the loss of accuracy of water meters and registers over time.

The present value of the total water meter monthly service charges is $1,927 per household.

\[
PV = A \left( \frac{(1 + i)^N - 1}{i(1 + i)^N} \right) + \sum F/(1 + i)^N \\
= 8.12 \times \left( \frac{\left(1 + \frac{0.03}{12}\right)^{30 \times 12} - 1}{\frac{0.03}{12} \times \left(1 + \frac{0.03}{12}\right)^{30 \times 12}} \right) + \sum_{N=1}^{30/15} \frac{1.50}{(1 + 0.03)^{15N}} = 1,927
\]

Thus, the present value of the water service charges total cost is $2,151.03 per household.

\[ PV = 224 + 1927 = 2,151 \]

Costs to the City of Raleigh

I developed a preliminary design for the water line extension based on the Handbook of the City of Raleigh Public Utilities Department\textsuperscript{25}. 

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I did not have information on the Raleigh population’s household water demand or flow through the distribution network, so I simulated the target community water demand and its effects on pressure in the water distribution system using the City of Raleigh Public Utilities Department’s water distribution model. From the simulation, I obtained a value of available fire flow of 3,100 gallons per minute at the target site and the maximum daily demand pressure at the target site of 65 psi, which satisfies the minimum requirement of 20 psi\textsuperscript{25}.

I selected a 6-inch water main for the municipal water service system extension. As discussed previously, I estimated the average daily water demand of the target community at 96 gallons per capita per day. Using a peak hourly factor of 1.4, the maximum daily water demand is therefore 134.4 gallons per capita per day, which results (as shown below) in a target community maximum daily water demand of 940.8 gallons per day.

\[
\text{maximum daily water demand} = 134.4 \text{ gallons per capita per day} \times 7 \text{ persons} \\
= 940.8 \text{ gallons per day}
\]

Thus the maximum flow velocity will be 0.007414 ft/s, which is less than 1.6 ft/s\textsuperscript{25}; hence, the 6 inch water main will fulfill the community water demand.

\[
\text{maximum flow velocity} = \frac{940.8 \text{ gallons per day}}{\frac{1}{4} \pi (6 \text{ inches})^2} = 0.007414 \text{ ft/s} < 1.6 \text{ ft/s}
\]

As mandated by the Handbook of the City of Raleigh Public Utilities Department, a hydrant and a gate valve will be installed at the end of the pipeline\textsuperscript{25}, and a gate valve and tapping sleeve will be installed at the extension of the pipeline and the existing municipal water system\textsuperscript{25} (Figure 5).
Figure 5. Extension of Municipal Water Service System in the Target Community

The City of Raleigh, as detailed in its Handbook, requires that backfill of pipeline be tamped in 6-inch lifts to the ground surface for concrete pavement patches\(^{25}\), and for side clearance the minimum requirement is 6 inches\(^{25}\). I therefore estimated the total backfill needed as 44 cubic yards, as shown below.

\[
\text{total backfill needed} = \left[ (6\ \text{inches} \times 2 + 6\ \text{inches}) \times (6\ \text{inches} + 6\ \text{inches}) - \frac{1}{4}\pi (6\ \text{inches})^2 \right] \times 900\ \text{feet} = 44\ \text{CY}
\]

On the basis of the target community topography, from the connection to the neighboring municipal water service system to the end of the pipeline extension, the elevation of the ground surface is raised from 380 feet to 393 feet, then depressed to 387 feet, and raised to 400 feet. Thus, two blow-off assemblies will be needed, based on the target community topography (Figure 6).
Figure 6. the Pheiffer Drive Community Topography

Costs for each component of the water service system connection discussed above were based on costs for a similar, recent water extension project in the City of Raleigh (City of Raleigh Public Utilities Department bid tabulation for 2011 water main replacement project #4A\textsuperscript{30}).

In total, I estimated the costs for municipal water service system connection construction as $104,243 (Table 11).
Table 11. Construction Costs for a Municipal Water Service System Connection

<table>
<thead>
<tr>
<th>Items</th>
<th>Estimated Quantity</th>
<th>Units</th>
<th>Unit Price ($)</th>
<th>Extended Item Price ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonds, insurance, mobilization, 2% Max</td>
<td>1</td>
<td>LS</td>
<td>3,000.00</td>
<td>3,000.00</td>
</tr>
<tr>
<td>6&quot; diameter water line</td>
<td>900</td>
<td>LF</td>
<td>35.72</td>
<td>32,148.00</td>
</tr>
<tr>
<td>6&quot; gate valves assembly</td>
<td>2</td>
<td>EA</td>
<td>1,000.00</td>
<td>2,000.00</td>
</tr>
<tr>
<td>Tapping sleeve and valve 6&quot; x 6&quot; with 6&quot; valve</td>
<td>1</td>
<td>EA</td>
<td>3,000.00</td>
<td>3,000.00</td>
</tr>
<tr>
<td>Connection to existing water main</td>
<td>1</td>
<td>EA</td>
<td>1,200.00</td>
<td>1,200.00</td>
</tr>
<tr>
<td>Blow-off assembly</td>
<td>2</td>
<td>EA</td>
<td>2,300.00</td>
<td>4,600.00</td>
</tr>
<tr>
<td>6&quot; line stop assembly</td>
<td>1</td>
<td>EA</td>
<td>4,849.56</td>
<td>4,849.56</td>
</tr>
<tr>
<td>Fittings</td>
<td>60</td>
<td>LB</td>
<td>3.71</td>
<td>222.60</td>
</tr>
<tr>
<td>Fire hydrant assembly</td>
<td>1</td>
<td>EA</td>
<td>3,200.00</td>
<td>3,200.00</td>
</tr>
<tr>
<td>Rock excavation</td>
<td>30</td>
<td>CY</td>
<td>300.00</td>
<td>9000.00</td>
</tr>
<tr>
<td>Concrete driveway repair</td>
<td>370</td>
<td>SY</td>
<td>90.00</td>
<td>33,300.00</td>
</tr>
<tr>
<td>Stabilization stone</td>
<td>0.3</td>
<td>TON</td>
<td>37.03</td>
<td>11.11</td>
</tr>
<tr>
<td>Select backfill</td>
<td>44</td>
<td>CY</td>
<td>31.59</td>
<td>1,389.96</td>
</tr>
<tr>
<td>Cleanup and seeding</td>
<td>1</td>
<td>LS</td>
<td>4,822.20</td>
<td>4,822.20</td>
</tr>
<tr>
<td>Erosion control measures</td>
<td>1</td>
<td>LS</td>
<td>4,500.00</td>
<td>4,500.00</td>
</tr>
<tr>
<td><strong>Total construction cost</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>104,243</strong></td>
</tr>
</tbody>
</table>
CHAPTER III: COMPARISON OF TECHNICAL OPTIONS

To compare the costs and benefits to the target community residents and the City of Raleigh government, in this report, I use “-” to represent positive costs and “+” to represent positive benefits.

Option 1

I estimate the total costs for option 1 at $29,080, consisting exclusively of the health costs of preventable AGI cases. These costs will be borne only by the target community residents.

Option 2

I estimate the total costs for option 2 at $18,916 per household, including the purchase costs only. The total costs for the community is $75,664, which will be borne only by the target community residents.

Option 3

The present value of the total cost of option 3 is composed of the household well water filter system installation, operation, and maintenance cost ($65,044) and the Wake County Human Services Laboratory’s fees for well water testing ($10,744). The total costs to target community residents therefore are $75,789 (Table 12). There is zero cost to the city under this option.

<table>
<thead>
<tr>
<th>Table 12. Costs for Option 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

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Option 4

The present value of Option 4’s total cost is composed of the well maintenance and repair costs ($274,406), the well water disinfection costs ($63) and the well water testing fees ($10,744). The first two charges will be borne by the target community residents, and Raleigh City government will receive the last item as income. Thus, the net benefits to residents are -$285,213, and the total benefit to the government is $0 (Table 13).

<table>
<thead>
<tr>
<th>Component</th>
<th>Component Cost ($)</th>
<th>Total Cost per Household ($)</th>
<th>Total Community Costs ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well Maintenance and Repair</td>
<td>Well Company Service Fees</td>
<td>68,602</td>
<td>68,602</td>
</tr>
<tr>
<td></td>
<td>Disinfectants Costs</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Environmental Service Fees</td>
<td>980</td>
<td>2,686</td>
</tr>
<tr>
<td></td>
<td>Well Water Analysis Fees</td>
<td>1,706</td>
<td>1,706</td>
</tr>
<tr>
<td></td>
<td>Net Benefits to Government</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Option 5

The present value of the total cost of connecting to a neighboring municipal water service system is composed of application fees ($8,952), water consumption charges ($18,524), water service charges ($8,604) and construction fees ($104,243). The first three items are paid by the
target community residents to Raleigh City government. The construction fees will be paid by the government. Thus, the net benefits to target community residents are -$36,080, the net benefits to government are -$68,164 (Table 14).

<table>
<thead>
<tr>
<th>Item</th>
<th>Total cost per household ($)</th>
<th>Total community cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application Fees</td>
<td>2,238</td>
<td>8,952</td>
</tr>
<tr>
<td>Water Consumption Charges</td>
<td>4,631</td>
<td>18,524</td>
</tr>
<tr>
<td>Water Service Charges</td>
<td>2,151</td>
<td>8,604</td>
</tr>
<tr>
<td>Construction Costs</td>
<td>-</td>
<td>104,243</td>
</tr>
</tbody>
</table>

**Table 14. Costs for Option 5**

<table>
<thead>
<tr>
<th>Item</th>
<th>Net Benefits to Residents</th>
<th>Net Benefits to Government</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connection to Neighboring Municipal Water Service System</td>
<td>-36,080</td>
<td>-68,164</td>
</tr>
</tbody>
</table>

**Technical Option Recommendation**

I compared the five technical options on the basis of net benefits to target community resident and to Raleigh City government (Table 15).

<table>
<thead>
<tr>
<th>Option</th>
<th>Net benefits to residents ($)</th>
<th>Net benefits to government ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option 1: no action</td>
<td>-29,080</td>
<td>0</td>
</tr>
<tr>
<td>Option 2: bottled water delivery</td>
<td>-75,664</td>
<td>0</td>
</tr>
<tr>
<td>Option 3: household well water filter system installation plus well water testing</td>
<td>-75,789</td>
<td>0</td>
</tr>
<tr>
<td>Option 4: well maintenance and repair plus well water disinfection plus well water testing</td>
<td>-285,213</td>
<td>0</td>
</tr>
<tr>
<td>Option 5: connection to neighboring municipal water service system</td>
<td>-36,080</td>
<td>-68,164</td>
</tr>
</tbody>
</table>
For option 1, since most target community residents are elderly, their health is more likely to be affected by AGI and its complications, because the elderly have higher susceptibility to infectious diseases. Their actual medical costs therefore could be higher than the estimation. However, since some will be retired and thus not working, the actual productivity losses could be lower than estimated. In the long term, without any actions to improve the drinking water quality, health costs will be generated continuously beyond the time frame considered in this report, which will increase the costs to the community residents.

For option 2, bottled water delivery may provide safe drinking water for the target community residents. However, this option may not provide sufficient protection for the target community residents. The residents can still intake unsafe well water from their bathroom taps and cook with the water.

For option 3, the multiple stages of the filter system may be effective in guaranteeing well water quality. The replaceable components also make it a long lasting filter. However, at the same time, the complexity of the filter system and the required periodic updates decrease the ease of operation and maintenance for the residents. The required professional labor work sharply increases the total costs of household well water filter system installation over the period of 30 years (the labor fees for components replacement composes 48.5% of the total costs of the filter system). The consequent high operation and maintenance costs may lower the residents’ willingness to select this technical option.

For option 4, the total cost for residents is significantly higher than those of the other options, which will lower the residents’ willingness to choose this option. In addition, since most residents likely lack the skills necessary to conduct proper well water disinfection, and improper well water disinfection may cause health issues, extra health costs may be generated.
For option 5, a qualified laboratory conducts routine and reliable water quality analytical testing for public water systems\textsuperscript{32} and provides water quality test results and reports, to which the public has access\textsuperscript{33}. The municipal water service system’s monitoring and record systems can ensure safe drinking water for its customers. Also, due to the public water service system’s greater water storage and pumping capacity, providing sufficient water to meet household water demand can be guaranteed even under extreme conditions, such as drought or power outages. However, pipeline erosion and leakage over a 30-year period may generate economic losses due to extra long-term water main maintenance and operation.

For the target community residents, their willingness to adopt any of the technical option conduction will decrease with increasing costs. Additionally, the effectiveness of each technical option will decrease with the decreasing ease of operation and maintenance. Thus, option 1 and option 5 would be preferred by the target community residents for their relatively lower costs (the costs of other technical options are at least twice of the costs of option 1 and option 5) and high ease to operate and maintain. However, only option 5 protects the community from exposure to the types of microbiological contaminants previously observed in Wake County ETJ neighborhoods.

Option 5 will impose substantial costs on the City of Raleigh government. Nonetheless, extending water service to this community would eliminate a historical racial disparity.

In conclusion, I recommend Option 5 as the best long-term solution to drinking water quality improvement for the residents in the target community. It has the lowest cost to residents other than no action. In addition, among the options other than no-action, it will be easiest for residents to implement. The no-action alternative is not preferred due to the evidence of compromised microbiological water quality in this community.
Sensitivity Analysis

As recommended by Office of Management and Budget Circular A-94\(^7\), I performed a sensitivity analysis for each technical option, using a discount rate of 7\% (Table 16). The change of discount rate to 7\% has no effect on the relative ordering of costs among options, so the choice of option should be insensitive to this change in discount rate.

<table>
<thead>
<tr>
<th>Option</th>
<th>Net benefits to residents ($)</th>
<th>Net benefits to government ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option 1: no action</td>
<td>-18,410.82</td>
<td>0.00</td>
</tr>
<tr>
<td>Option 2: bottled water delivery</td>
<td>-47,950.55</td>
<td>0.00</td>
</tr>
<tr>
<td>Option 3: household well water filter system installation plus well water test</td>
<td>-50,668.73</td>
<td>0.00</td>
</tr>
<tr>
<td>Option 4: well maintenance and repair plus well water disinfection plus well water test</td>
<td>-181,357.85</td>
<td>0.00</td>
</tr>
<tr>
<td>Option 5: connection to neighboring municipal water service system</td>
<td>-25,648.55</td>
<td>-68,163.51</td>
</tr>
</tbody>
</table>
CHAPTER IV: IMPLEMENTATION OF TECHNICAL OPTIONS

Option 1

Under this option, no implementation action is required. However, this option is not recommended, because it fails to ensure that the community has access to water that meets the requirements of the U.S. Safe Drinking Water Act. As previously mentioned, water sampling in similar communities in Wake County has revealed high concentrations of microorganisms that indicate the potential presence of fecal contamination. This is an elderly community and therefore may be especially vulnerable to infection risk from microbiological contamination.

Option 2

Under this option, each household would purchase delivered purified bottled water from Crystal Springs every half month. However, this option is not preferred. It is more costly than option 5, it may not provide sufficient protection for the residents if they inadvertently or intentionally continue to drink or cook with tap water.

Option 3

Under this option, each household would need to purchase a household well water filter system produced by Aquasana. The filter system would be installed by Mr. Rooter Plumbing Company. The filter system components would need to be replaced periodically. Components would be replaced by Mr. Rooter Plumbing Company every 3 months. To ensure the intended performance of the filter system, Wake County Human Services Laboratory would conduct annual well water quality tests for each household.
For this elderly community, the ease of operation and maintenance of the filter system will be sharply decreased, due to the complexity of replacing filter components. The high costs of operation and maintenance fees caused by professional labor work will lower the residents’ willingness to choose this option. Additionally, previous studies have shown that, rather than ensuring high-quality water, point-of-use devices can amplify the numbers of bacteria as biofilms grow on the filter components. Also, annual well water quality tests are not effective in detecting episodic contamination. Failing to detect and respond to contaminants will increase the health risks for the community residents. Furthermore, previous studies have shown that even if residents are provided with water quality results that indicate contamination, a portion of households (nearly one third) take no action in response. Therefore, monitoring at frequencies greater than yearly may not provide a sufficient guarantee of water quality for this community.

**Option 4**

Under this option, private well systems in each household would be maintained and repaired by American Water Resources. Homeowners would conduct annual well water disinfection with calcium hypochlorite.

The high price ($68,601.54 for each household over the period of 30 years) of well maintenance and repair will notably weaken the willingness of elderly community residents to insist on this technical option. In addition, because of the professional skills required for the application of well water disinfection, the elderly community residents may not be able to conduct proper disinfection, which may lead to extra health issues.
Option 5

To connect to the neighboring municipal water service system, the community house owners would need to submit an application form and fees to the City of Raleigh Development Service. The Raleigh government would then arrange the pipeline construction project, which would proceed as pre-construction survey, clearing and grading, trenching, pipe stringing, welding and coating pipe, lowering pipe in and backfilling, testing, and restoration.36

Under this technical option, the Raleigh government would bear the municipal extension construction costs of $104,243.43 over the period of 30 years, which may obstruct the Raleigh government’s approval of this project. The city would recoup part of this cost as one-time connection fees and from the payment of water bills. In addition, if the community is annexed into the city, the city would gain increased tax revenue (not calculated here). A drawback of this option is that the anticipated long pipeline construction period (usually 24 months) may expose the community residents under unsafe well water in the interim.

Conclusion

I compared the four technical options for the improvement of drinking water quality in the Pheiffer Drive community on the basis of costs and benefits to both homeowners and the government of the City of Raleigh, health risks, and the ease of operation and maintenance for homeowners.

Without municipal water service, households would need to take responsibility for their drinking water safety and bear the costs of well water quality tests and treatment. Evidence from previous studies suggests that many homeowners would be unlikely to conduct the testing and install and maintain the treatment systems needed to ensure the quality of their water, even if
provided with evidence of contamination. Furthermore, the long-term maintenance of point-of-use filters and the need to ensure regular water quality testing would pose a burden on homeowners. Therefore, I recommend connecting to the neighboring municipal water service system as the best long-term solution to ensuring water quality in this community. It is the lowest cost option for the community ($36,079.92) other than taking no action.
References


