Perceptions of Water Scarcity in Charlottesville, Virginia

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Abstract

The crisis of water scarcity is becoming increasingly prevalent across the globe. Water shortages can be derivative of climate change induced rising temperatures and prolonged droughts, improper management of freshwater resources, inadequate water infrastructure, and a demand for water that exceeds the supply due to population growth. Specifically, water scarcity was an issue in the summer of 2002 in Charlottesville, Virginia. An extended drought caused the city and county water suppliers to set water use restrictions. The water shortages impacted the livelihoods of residents and caused a decrease in net economic output of local businesses. From that point forward, water supply planning was initiated to prevent future water scarcity in Charlottesville. Proving success, Charlottesville has not experienced significant water shortages since 2002.

To better understand the public perceptions of water shortages and the associated solutions, survey research is commonly conducted. Through the distribution of 156 questionnaires in Charlottesville, Virginia, the research presented discusses reactions, perceptions, and solutions for water scarcity by Charlottesville residents. The questionnaires were distributed through convenience sampling techniques of tabling and flyering. The results of the survey suggested that Charlottesville residents are more knowledgeable about water scarcity compared to national averages, Charlottesville residents are less likely to complete water conservation practices than those affected by water scarcity, Charlottesville residents are open to increased water conservation education, and Charlottesville residents may be willing to partake in indirect potable water reuse. The research suggests that Charlottesville is water abundant due to proper

local institutionalized water management, paired with conservation measures by Charlottesville residents.

Introduction

The information presented describes topics related to water scarcity as well as relevant and similar studies pertaining to water scarcity research. The topics include water scarcity and its increasing prevalence, the impacts of water scarcity, American water infrastructure and management, American water consumption, water level management and conservation in Virginia, water level management and conservation in Charlottesville, Virginia, how surveys are used to understand water scarcity perceptions, national water scarcity surveys, surveys about water context and attitudes toward water conservation, individual water conservation surveys, surveys that discuss perceptions to water scarcity solutions, and research gaps, in that order.

Because this project was conducted in Charlottesville, VA, United States, a majority of the background literature focuses on water supply and management in the United States, and Charlottesville, Virginia.

Water Scarcity & its Increasing Prevalence

Water is an integral component of everyday life. However, in some regions, the supply is diminishing. The IPCC reports that approximately half of the global population is suffering from severe water scarcity for a minimum of one month per year, due to the climate and other factors (IPCC, 2022). Unfortunately, water shortages will be exacerbated as the impacts of climate change continue to create global impacts.

For example, climate change induced drought (lower precipitation) causes a reduction in raw water availability, in turn causing reduced river flows, and thus lowering the dilution of pollutants in local water bodies (UN, 2010). The reduction in river flow from climate change is primarily a result of warmer temperatures inducing an increase in evaporation from water bodies and soil moisture (Chen & Hu, 2004). When precipitation occurs during periods of increased soil moisture evaporation, a higher quantity of water absorbs into the soil, as opposed to greater surface runoff entering water bodies (Chen & Hu, 2004).

When an increase in temperatures from climate change causes heat waves, infrastructure damage can occur, leading to pathogens in the water. As glaciers, snow, permafrost, and sea ice thaw or melt, the seasonal changes in river flows can lead to a lower supply of water in the summer to communities (UN, 2022). In cases where climate change stimulates increased precipitation, flooding may occur, which can cause pollution of wells from overflow, damage to infrastructure (and specifically water infrastructure), landslides in areas with raw water sources, sedimentation and turbidity in water sources, and waterborne diseases (UN, 2022). For every individual degree Celsius increase from global warming, there is an estimated 20% reduction in renewable water resources (Cisneros et. al, 2014).

In addition to increasing average global temperatures, population growth may also perpetuate water insecurity. Population growth continues to increase, with an estimated 9.7 billion people projected to be living on planet Earth by 2050. Considering that water insecurity is pervasive with the current global population of roughly 8 billion people, it is likely that the issue will worsen in the future if best practices are not established and maintained.

Through climate modeling conducted by the USGS, Virginia is expected to have increased temperatures, although the extent by which that is experienced varies predominantly on the quantity of greenhouse gas emissions released into the atmosphere (Virginia DEQ, 2022). Virginia droughts generally occur when minimal winter precipitation occurs in tandem with increased evaporation rates from higher temperatures in the summer and/or minimal summer precipitation (Virginia DEQ, 2022). Within the last 30 years, Virginia has holistically experienced increased temperatures and evaporation rates (Virginia DEQ, 2022). Although climate change is expected to increase precipitation rates, evaporation rates are continuing to increase at an unsustainable level, ultimately increasing the intensity of future droughts (Virginia DEQ, 2022). Therefore, it is essential to devise best practices for water management and conservation now within the state.

Impacts of Water Scarcity

Water scarcity is commonly separated into two categories: physical scarcity and economic scarcity (Liu et. al, 2023). Physical scarcity is when there are water shortages from regional environmental conditions, whereas economic scarcity is derivative of a lack of sufficient water infrastructure (Liu et. al, 2023).

Water shortages threaten agricultural production, energy generation, and public health. Additionally, because water impacts a myriad of sectors, as water insecurity increases, geopolitical conflicts over water are expected to rise simultaneously (Petersen-Perlman, 2016).

Water is essential for crop cultivation, so a decrease in water may equate to further food insecurity. When droughts and intense heat waves occur on agricultural lands, the harvest may be less bountiful due to the resource's depletion. Therefore, socioeconomic issues arise from increasing food prices and/or general food insecurity (in the case of inadequate left-over food storage) (Mohamed, 2019).

Pertaining to energy generation, hydropower is a popular resource. According to the United States Department of Energy (US DOE) hydropower accounts for ~29% of renewable energy generation and ~6% of the aggregate electricity for the nation (n.d.). When water levels and flow velocities decrease in a river, electricity generation can decrease. For example, during drought conditions between 1999 and 2003, electricity generation from hydropower dams along the Colorado River decreased over 20%, in turn increasing electricity bills in addition to the issue of water scarcity (Richter, 2014).

In terms of public health, inadequate water supplies often translate to inadequate sanitation. This is due to the use of water for bathing, washing one's hands, and cleaning one's garments or dishes, among other activities. Additionally, diseases can be contracted by those who are consuming water that may contain pathogens, due to a lack of safe drinking water in the area. (Tarrass, 2011). Increased disease equates to increased mortality rates.

American Water Infrastructure and Management

Water scarcity can occur in both less developed countries and more developed countries because of a lack of proper water infrastructure and management. For example, in 2011, researchers at Utah State University conducted a survey of 188 utility providers to inquire about water main failures in the United States and Canada. The results determined that approximately 43% of the installed pipe for water systems were between 20 to 50 years old and 22% were over 50 years old (Folkman et. al., 2012).

For the sake of narrowing the research to the nation where the research is conducted, it is important to understand the holistic state of American water infrastructure systems. In the United States, the water infrastructure system is considered to be "aging and underfunded" by the American Society of Civil Engineers (ASCE). Similarly, the United States Environmental Protection Agency (US EPA) states that the nation's water infrastructure is "aging and in need of repair" (US EPA, 2018). The ASCE reported that a water main break occurs every 2 minutes, with an expected 6 billion gallons of treated water lost per day (ASCE, 2021).

In 2018, the U.S. EPA estimated that an investment of $472.6 billion dollars into national water systems is required by 2035 in order to provide safe drinking water throughout the United States. Of that sum, $47.6 billion should be allocated to construct, rehabilitate, or cover water storage reservoirs (involving management practices) (US EPA, 2018). However, in the U.S. EPA's most recent report called the *7th Drinking Water Infrastructure Needs Survey and Assessment April 2023*, they estimated that an investment of $625 billion dollars into national water systems is required by 2035 in order to provide safe drinking water throughout the United States. This is over 32%

higher than the report from 2018. Being that the average annual number of water main breaks in America is between 250,000 to 300,000, a lack of adequate water infrastructure poses a contamination and supply threat to the nation's drinking water (American Society of Civil Engineers, 2021). Water scarcity is an essential issue to address in the United States on a national scale.

The Biden Administration of the United States has made investments in water systems through the allocation of $50 billion to support their Investing in America Agenda and the Bipartisan Infrastructure Law. The funding will go towards replacing lead pipe systems (contamination reasons), increased drinking water infrastructure, and increasing water system product manufacturing in the nation (The White House, 2023). However, greater repeated investments will be necessary until 2035, if the United States population wants to achieve the estimated necessary investments into water infrastructure of 625 billion dollars by 2035.

American Water Consumption

Every five years, the U.S. Geological Survey (USGS) records and analyzes water use data in the United States and its associated territories. The most recent data is from 2015 because they are likely currently conducting data analysis or in the publication process for data from 2020. In 2015, approximately 322 billion gallons of water was withdrawn in America. This continued the declining trend of water consumption since 2005, although the population increased by ~8.5%. According to the USGS, the predominant reasons for the downward trend are increased efficiency in the water use practices of thermoelectric power plants and closures of plants with once-through cooling systems (2015).

The three largest sources of water withdrawals in the United States are from thermoelectric power, irrigation, and for the public supply, respectively. USGS calculated in their most recent report that for 2015, thermoelectric power withdrew the greatest percentage of water from United States water bodies, being 41% (2018). In Virginia specifically, thermoelectric power makes up the greatest percentage of withdrawals. To be noted, the electricity generation did not consume the water, rather, a majority of the water was recycled. However, irrigation, accounting for 37% of withdrawals, consumed approximately 20 times more water, due to factors like evaporation (USGS, 2018). The third greatest cause for withdrawal is for the public supply, which accounts for approximately 12% of United States total water withdrawals. Public supply is generally used for domestic, industrial, and commercial use (USGS, 2018).

Water Level Management and Conservation in Virginia

In Virginia, water supply planning has become a priority for the state, especially in an effort to address potential climate change scenarios for differences in precipitation and evaporation rates (Virginia DEQ, 2022). Virginia's Department of Environmental Quality (DEQ) requires the local governments of counties, cities, and towns in the state of Virginia to propose a water supply plan every 10 years (2022). The Water Supply Plan (WSP) program was created to address the intense Virginia droughts of 2001 and 2002 and has been successful in attaining the necessary data thus far (Virginia DEQ, n.d.). Each WSP states where the locality obtains their water sources, as well as the current and estimated future water consumption of said sources (Virginia DEQ, n.d.). Finally, the plan requests that the locality evaluate the sufficiency of the current water sources and devise a best management strategy in the case that the source is no longer available (Drought Response and Contingency Plans). This way, the state of Virginia can consider creating new forms of storage, redundant water source systems, and diversifying water sources as necessary (Virginia DEQ, n.d.).

Water Level Management and Conservation in Charlottesville, Virginia

In a report published by the ASCE called *The Report Card for Virginia Infrastructure*, ASCE noted that the capacity of drinking water treatment plants and networks in Virginia is sufficient due to the abundance of natural sources such as rivers, lakes, and groundwater systems (2022). Notably, in a section entitled *Resilience* within the *Drinking Water* chapter, the Rivanna Water and Sewer Authority in Charlottesville was highlighted to discuss improvement of resilience through conservation programs. Furthermore, the water quality in Charlottesville is considered to exceed all safety standards and does not pose a threat to public health. This is in part due to the fact that there are not any lead service lines found within the city (City of Charlottesville Utilities, 2023). Lead service lines are posing a threat to public health, as the aged lead contaminates the water supply as it travels through the system. Thus, Charlottesville is considered to be a location with proper water infrastructure practices.

Charlottesville Water is the entity that installs, maintains, and repairs all of Charlottesville's water distribution main systems, valves, fire hydrants, and water meters. This accounts for 183 miles of serviced water mains, 3,400 valves, and 1,100 fire hydrants as of the most recent data from 2020. The city uses potable water and sanitary sewer systems and encourages water conservation through rebates and incentives. For example, they offer rain barrel rebates, efficient water consumption toilet rebates, as well as free water conservation kits that include water efficient faucet aerators, showerheads, and toilet leak detection tablets. Found in the Charlottesville Water Conservation 2022 Highlight Report, 84 toilet rebates were issued in 2022, saving approximately 68.9 million gallons of water annually (Charlottesville Water Conservation, 2022). Additionally, the Charlottesville Water Conservation Program received two 2022 Public Information Awards in the categories of water awareness and education as well as in social media from the Virginia Section of the American Water Works Association. Finally, the U.S. EPA awarded Charlottesville with a 2022 WaterSense Sustained Award for Charlottesville's commitment to community water conservation. This award is the highest offering available (City of Charlottesville, N.D.).

The Rivanna Water and Sewer Authority (RWSA) is responsible for water treatment for the City of Charlottesville (City of Charlottesville, N.D.). The two main sources of water are South Fork Rivanna Reservoir and Ragged Mountain Reservoir (City of Charlottesville, 2023). As of September 25, 2023, the usable capacity of these urban reservoirs was calculated to be 92.46%, further providing evidence for a lack of water scarcity in Charlottesville (Rivanna Water & Sewer Authority, 2023).

In 2002, an intense drought occurred in the Central Virginia Region which caused the Charlottesville/Albemarle water suppliers to set water use restrictions, which impacted the livelihoods of residents and the net economic output of local businesses. As a result, the locality decided to create a water supply planning process between 2002 and

2012, leading to the Community Water Supply Plan. Thus, the City of Charlottesville presently has robust operations to ensure a sufficient water supply to the populations, as demonstrated by approval by the U.S. Army Corp and The Department of Environmental Quality (DEQ) (Rivanna Authorities). Today, there are ongoing operations of the plan including short-term management programs for voluntary and mandatory water use restrictions and curtailment during temporary drought conditions (Rivanna Authorities, 2022).

How Surveys are Used to Understand Water Scarcity Perceptions

Survey research is commonly conducted to gauge beliefs from the public on various topics, as well as to best select solutions to issues that affect the public (like water scarcity). Survey collection varies regarding how participants are selected and how the data is collected (Ponto, 2015). Surveys can include quantitative methods with numerically rated questions, qualitative research methods that inquire for short answer responses, or both for a mixed methods approach (Ponto, 2015).

Survey research is generally used to determine the characteristics of large populations in a rapid manner (Ponto, 2015). Large random sampling increases the probability that the sample population will reflect the desired population. This is important so the data may be used to form accurate deductions about the population.

Questionnaires and interviews are common data collection methods to survey a population. Oftentimes, surveys include demographic questions in an attempt to mimic the larger population. Questionnaires can be in a paper format and mailed to potential participants or they can be formatted electronically and distributed through email, text, and/or online forums. (Ponto, 2010). Generally, increased survey methods equates to decreased coverage error. This is because it creates greater opportunity for individuals in the sample population to come across the survey. Typically, a sample size between 100 and 200 corresponds to a margin of error between seven and ten percent at an assumed 95% confidence interval, assuming that the population is larger than the sample (Hunter, 2016). A confidence interval of 95% is the widely accepted industry standard (Hunter, 2016).

To decrease nonresponse bias for online questionnaires, it is suggested to utilize a suitable font size, a logical ordering of survey questions, and formatting the questions in a clear manner on the site (Dillman et al., 2014).

For recruitment purposes, sometimes non-probability sampling is used. Non-probability sampling is when there is a disproportionate opportunity for some members of the population to be selected for the data collection than others. Non-probability sampling is used, as opposed to probability sampling, when the researcher may not have the time, resources, or enough accessible information to conduct a study with a sampling frame. A sampling frame is a list of those within a population that is to be sampled from, which may include the names and addresses of those within the population. An example of non-probability sampling that is commonly used is known as convenience sampling.

Convenience sampling, also known as availability or accidental sampling, is when members of the target population are highly accessible to the researcher and meet the needed criteria of the study (Galloway, 2005). Oftentimes, they are selected due to high accessibility to the researcher, being located near the researcher, their willingness to be involved in the study, and their availability during the time of sampling (Galloway, 2005). Common forms of convenience sampling include the use of survey respondents from online panels and tabling.

It is important to note that one can only make weak assumptions about the larger population based on the research from a convenience sample (Galloway, 2005). This form of sampling allows individuals to self-select into the data set, which can form major biases, as those that are interested in participating in the study may be the individuals with more extreme opinions. One can draw conclusions based on the data given by the convenience sample, but must emplore that the predominant assumption being made is that the research results would not differ drastically than if taken through a probabilistic sampling like random sampling. That is, drawing conclusions upon the data disregards and does not quantify biases of the sample. An increase in sample size can decrease potential bias for convenience sampling methods (Etikan et. al, 2016).

A common form of probability sampling involves sending questionnaires via postal mail. However, this form of outreach typically has high non-response rates and follow up measures add to the cost of the project. Therefore, in person convenience sampling such as tabling generally has lower non-response rates and may be less expensive than paying for postage (Galloway, 2005).

In regards to water scarcity work, surveys are conducted to understand public beliefs on water conservation practices and preferred solutions to water scarcity. However, previous literature does raise significant gaps in the beliefs of water scarcity due to the lack of specificity of populations because of the conduct over broad regions and the lack of survey perceptions by those in unaffected populations.

Although published in 2010, researchers Sally Russel and Kelly Fielding from the University of Queensland, Australia have stated that there is an increased demand for water management research, specifically in regards to environmental psychology for residential water demand. The research at hand has been designed in a manner to bridge this gap, specifically for that of Charlottesville, Virginia.

National Water Scarcity Surveys

Many of the prior surveys reported in literature were conducted over broad regions, as opposed to smaller regions, like a city. For example, previous literature involves national surveys that are meant to be representative of the American population's perceptions on water scarcity. Specifically, predominant gaps in the most publicized national surveys include the following: unclear methods due to the findings being unavailable to the general public and that the research organizations may have potential bias.

For example, SUEZ Water Technology Solutions distributed 2,000 questionnaires to continental American residents to better understand their water scarcity perceptions and water scarcity solutions (Veolia, 2020). SUEZ Water Technology Solutions used OnePoll, an international market research agency, to conduct the research on their behalf through online survey panelists. SUEZ Water Technology Solutions is a water technology company, so the questions may have been written in a way that promotes further water scarcity innovation, as that may increase their economic growth. There was no data available about the demographics of the sample, so it may not have mimicked that of the United States population proportionately.

Similarly, a survey completed by Grundfos, a water pump manufacturer, has been cited on multiple accounts for a questionnaire that they distributed to 2,000 Americans about water scarcity perceptions. The results can be found on various blogs and news sources (PR Newswire, 2017). However, the methods section of the report cannot be located publicly, to the best of the researcher's knowledge (PHCP Pros, 2017). Additionally, the survey results may be outdated because it was taken in 2016, approximately 7 years ago at the time of this report's publishing. Although some sources say that the conduct of the survey was meant to represent various regions of the United States, again, the methods by which the researchers used are not able to be found, thus, the sampling may have been biased or disproportionately representing different parts of the United States. Both questionnaire results may not be an adequate representation of national water perceptions.

Because, to the best of the researcher's knowledge, there have been limited questionnaires about water scarcity perceptions, the results and methods of international water scarcity questionnaires are pertinent to consider. In an assessment of community perceptions and adaptations to water scarcity in Coastal Bangladesh, researchers questioned Bangladeshi beliefs about the main causes of safe water shortages and the extent by which they have been facing them. Similar to the questionnaires distributed by Grundfos and SUEZ Water Technology Solutions, the data from a random distribution of 240 questionnaires was meant to be representative of a broad region. The surveys were distributed so as to have 30 surveys for each of the 8 villages that represent the region. In this case, it was representative of the Bangladesh districts of Khulna and Satkkhira, which combined, have a population of 6.2 million residents (Abedin et al, 2014).

Currently, the inhabitants of Coastal Bangladesh are facing the issue due to a lack of safe drinking water from salinity, arsenic, and drought. According to the study, the surveyed population was those experiencing moderate and severe drinking water scarcities. However, the respondents may have been more likely to complete water conservation practices than those who are unaffected, being that they are actively facing the issue (Gilbertson et al., 2011) .

Furthermore, in a 2009 study completed by UNC researchers within the Department of Civil, Construction, and Environmental Engineering, the researchers aimed to discover public perceptions of water shortages, conservation behavior, and support for water reuse in the United States. The results from 2,800 respondents across the United States demonstrated that only 6.5% were identified as water concerned, 51% were water conservers, and 43% supported reclaimed water (Garcia-Cuerva, 2009). However, being that this study is more than a decade old, it is important to gauge water shortage perceptions in a more recent study.

The benefit of conducting questionnaires over a broad region is that the sample population can include people affected by water scarcity and those who are unaffected. This means that people of diverse perspectives and backgrounds may be participants. For example, in the United States, water scarcity is a predominant issue in the Southwest due to heat waves and intense drought conditions (Richter, 2014). In other areas, like Charlottesville, Virginia, common droughts have not been of concern and the available water levels have been generally stable (with the exception of the prolonged drought in 2002). Thus, perspectives from both parties may be received in a national survey to get a true average of American perceptions (if the methodology was executed properly).

For sake of a comparison to national water stress perceptions, the researcher will use both survey results from the Grundfos report and the SUEZ Water Technology Solutions report to compare and contrast the Charlottesville resident perceptions to the **potential** national perceptions to water shortages and potential mitigation measures. For primary national comparison, the researcher will use data from the Garcia-Cuerva study.

Surveys about Water Context and Attitudes Toward Water Conservation

Supporting evidence suggests that one's water context has an influence on their water conservation practices, which may in turn also cause differences in their perceptions of solutions. There have been previous studies that were conducted to observe the water conservation practices of a population. However, to the best of the researcher's knowledge, there is a limited quantity of recent questionnaires and research conducted to gauge water scarcity perceptions by **unaffected** populations. A common trend is to target studies towards perceptions of water scarcity in locations being actively affected. This raises a significant gap in data.

In a paper published in 2011 by professors of Architecture, Building, and Planning at the University of Melbourne, among others, the research was conducted to compare water conservation practices of two groups: individuals in Darwin, Australia experiencing a water surplus and individuals in Mallee, Australia facing a water shortage. The research was conducted through the use of an electronic survey company that has an active panel of respondents to select from that match the needed population demographics. If an individual on the panel was from Darwin or Mallee, then the individual was invited to participate via email and would receive compensation. The sample size included 195 responses from Darwin and 119 responses from Mallee. Therefore, the results are not necessarily statistically significant being that it was a non-probability convenience sample with a limited sample size.

The data from the research indicated that those faced with a water surplus are less likely to participate in water conservation behaviors than their counterparts (Gilbertson et. al, 2011). However, being that these results are more than a decade old, the difference between water conservation measures by those facing water scarcity and those not facing water scarcity may not be as prevalent. Thus, there is a need for more research to be conducted for individuals that are unaffected by a water crisis to make such deductions. For instance, there may be a possible increase in conservation measures by unaffected populations due to an increase in public awareness of water shortages; as global water shortages increase, so does their media publicization. For example, in 2010 (around the time of the Gilbertson et. al study) there was an estimated 884 million people who lacked access to safe drinking water, as opposed to the estimated 2 billion people who are affected in 2022 (UN, 2010; UN, n.d).

In 2014, a national survey of 1,020 participants distributed across the United States asked participants to report their perceptions of water use for household activities (Attari, 2014). The sample was obtained through Amazon's Mturk recruitment panel, similar to the study by Gilbertson. The results of the survey showed that most Americans believe that curtailment rather than efficiency improvements were the most effective strategies, disagreeing with expert opinions (Attari, 2014).

Individual Water Conservation Surveys

There is an extensive amount of recorded literature about water conservation practices, although the amount of literature on peer reviewed studies of conservation practices is more limited. Of particular interest, a national survey of 1,020 participants conducted in 2014 across the United States asked participants to report their perceptions of water use for household activities (Attari, 2014). The results of the survey showed that most Americans believe that curtailment rather than efficiency improvements were the most effective strategies, disagreeing with expert opinions (Attari, 2014). Although this source was conducted over a broad region, it is a helpful dataset to compare national averages to that of Charlottesville residents. This more accurately contributes to the understanding of perceptions of water scarcity and mitigation in comparison to national averages than the results by the studies from Grundfos and SUEZ Water Technologies.

Surveys that Discuss Perceptions to Water Scarcity Solutions

In a survey conducted in Albuquerque and Bernalillo, New Mexico, researchers attempted to understand perceptions of potable water reuse as a mechanism for addressing water scarcity in the region, in addition to questions about domestic conservation habits, water shortage perceptions, water quality perceptions, and climate change (Distler & Scruggs, 2020). The community survey was collected via mail or electronically to a random sample of 4,000 water utility account holders for Albuquerque and Bernalillo County Water Utility Authority. To mimic the population, the sample was formed in a way that each quadrant of the county had adequate representation. The research used SurveyMonkey to collect the data, upon approval by the New Mexico

Institutional Review Board. To ensure the results remained anonymous, the researchers aggregated the data with R Studio once collection was complete. The research conducted by Distler and Scruggs was completed so as to attain an exhaustive analysis of a set location, which is a research goal for this Charlottesville research as well.

The results of the survey suggested that respondents were open to potable water reuse. Specifically, 3% more survey respondents stated that indirect potable reuse was "generally okay" and 4% more considered themselves "very willing to drink" indirect potable water reuse, as opposed to direct potable reuse. Collectively, direct potable reuse had 28% of respondents say that they would "prefer to avoid" or "refuse to drink" from the source, as opposed to 17% of respondents for indirect potable reuse.

Research Gaps

Within the realm of water scarcity survey research, the predominant trends include that the surveys are **generally distributed over a broad region**, the survey sample populations are **facing water shortages at the time of data collection,** and the surveys **do not inquire about resident participation in specific local water scarcity solutions**.

Therefore, the objective of this study is to observe perceptions of water scarcity and the associated solutions by residents of a single, water abundant city during the time of data collection. The data collection targets specifically the city of Charlottesville, Virginia. This location was not considered to face water scarcity at the time of this paper's publishing, as represented by the water levels reported in November 2023 (Charlottesville Water, 2023). Furthermore, to the best of the researcher's knowledge, there is not any available data for Charlottesville residents' perceptions of water scarcity and the associated solutions. Therefore, the research addresses this gap.

The survey results discuss reactions, perceptions, and solutions for water scarcity of Charlottesville residents. The purpose of data collection is to gain a better understanding of whether Charlottesville is water abundant due to proper local institutionalized water management, Charlottesville resident water consciousness, or a combination of both. The survey attempts to observe the level of water consciousness that Charlottesville residents conduct, provide insight on resident obstacles to water conservation, and to better understand the preferred solutions for water scarcity by the Charlottesville population. Holistically, the survey data can be applied to the broader concept of how people who are unaffected by water scarcity perceive water scarcity solutions and conservation efforts. The data collected can be used by the local government to configure new methods by which to decrease water consumption or increase knowledge of water conservation. By observing possible correlations between knowledge levels of water scarcity within the populations of Charlottesville, a comparative study can be conducted between similar water scarcity perception surveys conducted in other sites.

The primary researcher hypothesized that Charlottesville is water abundant due to proper local institutionalized water management, as opposed to conservation measures by Charlottesville residents. The primary researcher hypothesized that the research would suggest that Charlottesville residents would not be as knowledgeable of water scarcity compared to the national averages or by those that are facing water scarcity. The primary researcher also hypothesized that Charlottesville residents would be less likely to complete water conservation practices, as opposed to their water scarce counterparts. The remainder of the paper discusses the methods by which the research was conducted, the survey results, a comparison of the survey results to the data collected through similar surveys, and a discussion of future research possibilities.

Methods

The research was conducted through the distribution of surveys to Charlottesville residents through availability sampling. The survey was completed between October 18 and November 6, 2023 at the Charlottesville Historic Downtown Mall, the Corner, and adjacent to Newcomb Hall at the University of Virginia, upon approval by the University of Virginia's International Review Board.

Completed questionnaires were attained through tabling and the posting of 15 fliers with QR codes in and adjacent to those areas. The fliers featured QR codes that were set to expire after 14 days. To avoid sampling error from potential participants scanning the survey from the posted QR code flier, the restrictions for being over 18 and a Charlottesville resident were listed on the flier and in the questionnaire agreement of the survey.

The research was conducted through non-random/non-probability convenience sampling (availability sampling) for cost and time efficiency. Completion of simple random sampling posed a challenge due to cost and the difficulty of attaining contact information of the public. For example, abundant time and economic resources are required retrieving each community member's email addresses or purchasing postage to mail the survey to every Charlottesville address.

The survey questions were categorized under 4 general areas: demographics, water shortage perceptions, water shortage solutions, and water management and conservation. These categories were selected to observe how a lack of water scarcity affects one's perceptions, knowledge, and awareness of water shortages in other regions. Additionally, the questionnaires were distributed to observe how local policy can affect one's perceptions of solutions for water scarcity prevention. The questionnaire was produced by the primary researcher, with specific questions garnering data similar to previous peer reviewed water scarcity questionnaires for data comparison. The questionnaire can be found in the appendix. The researcher formulated similar questions to those in the aforementioned **Distler and Scruggs survey, SUEZ Water Technology Solutions survey, Grundfos Survey, and the Garcia-Cuerva survey**.

The Charlottesville questionnaire similarly included multiple choice, multiple-select, ordinal, and short answer questions to ensure a comprehensive range of qualitative data. To have a larger range of questions and greater means of comparison, some questions were written similarly to the survey conducted by UNC researchers within the Department of Civil, Construction, and Environmental Engineering, as the researchers aimed to discover public perceptions of water shortages, conservation behavior, and support for water reuse in the United States (Garcia-Cuerva, 2009).

Being that the population of Charlottesville is estimated to be 45,373 as of 2022, the researcher attempted to retrieve a minimum sample size of 150 questionnaire respondents to attain an assumed confidence level of 95% and a margin of error of 8%, as that is the industry standard for both the confidence level and margin of error (United States Census Bureau, 2022). In an effort to maintain statistical validity of the sample population, the survey was only distributed to residents of the area. Because the Census Bureau considers college students as residents, University of Virginia students were eligible to participate in the survey.

The fliers were posted between Wednesday, October 18, 2023 and October 22, 2023. The primary researcher tabled on the following days:

- Wednesday, October 18, 2023 adjacent to Newcomb Hall at the University of Virginia between 3pm-7pm
- Thursday October 19, 2023 adjacent to Newcomb Hall at the University of Virginia, Saturday between 2pm-5pm
- Saturday, October 21, 2023 at the Charlottesville Historic Downtown Mall between 12pm and 2pm
- Saturday, October 21, 2023 at The Corner between 2pm and 3:30pm
- Thursday October 26, 2023 adjacent to Newcomb Hall at the University of Virginia, Saturday between 12pm-2pm

The primary researcher utilized a multi-mode design when tabling to reduce coverage error. The researcher administered paper versions of the questionnaires to those that preferred to, or were unable to, record their survey responses with the online Qualtrics platform.

In another effort to reduce coverage error, the Charlottesville Historic Downtown Mall, The Corner, and the site adjacent to Newcomb Hall were selected because they are considered high frequency locations for Charlottesville residents. Additionally, the sites are near bus stop locations, so transit dependent populations may be represented in the sample. To eliminate intentional response bias, the surveys were conducted anonymously.

Additionally, the survey was formatted to be brief to avoid nonresponse bias. To avoid sampling error when tabling, the primary researcher explicitly stated that the survey respondent must be over 18 and a resident of Charlottesville.

The data collection occurred for less than 4 weeks to maintain statistical validity and consistency with responses. The primary researcher had the intention to minimize variability in responses by keeping the season of survey distribution constant, as weather patterns like droughts or rainfall should also remain generally consistent during the period of data collection. The primary researcher chose to table during the given times, as students are commonly taking classes or consuming food at Newcomb Hall during those times. The primary researcher chose to table at the Charlottesville Historic Downtown Mall during that time period because it was the morning of the Charlottesville Farmers Market, to maximize community participation in the survey. Specifically, this paired timeframe and site were selected so as to maximize potential participation of Charlottesville residents that may live in more rural or distant parts of the city. The primary researcher varied the location, time, and day of data collection to provide an opportunity for more people to participate.

After data collection, the electronic Qualtrics questionnaires were compiled with the paper responses. Upon data collection, the results from the questionnaires were aggregated in Microsoft Excel and analyzed.

After synthesizing the data, the responses were compared to other survey responses to provide a broader understanding of how Charlottesville water scarcity perceptions compare to the perceptions of others from differing locations.

Results & Discussion

Sample Population Characteristics

The first 7 questions on the survey pertained to demographic questions, so as to identify the type of participants within the sample and observe how closely the sample mimics the Charlottesville population. The results of 4 of the questions are discussed in this section. It is pertinent to compare the sample population to that of the population of Charlottesville, so as to deduce similarities and differences. When the data is aggregated, it is not possible to discern which survey respondents of specific demographics did or did not answer questions. Due to the nonresponse answers, the sample cannot be entirely identified, but the following statistics can provide a satisfactory insight for characteristics of the sample.

The age distribution was divided in a manner to separate the population by defined generations suggested by the Pew Research Center. Individuals between the ages of 7 and 22 are considered Generation Z, individuals between the ages of 23 and 38 are considered Millennials, individuals between the ages of 39 and 54 are considered Generation X, individuals between the ages of 55 and 73 are Boomers, and individuals between the ages of 74-91 are known as the Silent Generation (Parker, 2023).

According to the survey results, a majority of the participants were between 18-22 years of age (~67% of the sample), ~13% of the sample were 23-38 years of age, 6% of the sample were between 39-54 years, 5% of the sample were between 55-73 years of age, and 9% of the sample did not respond to the question (Figure 1). There were not any respondents over 74 years of age that enrolled in the survey. The overrepresentation of

Generation Z respondents may have been due to each of the tabling locations being in areas of high traffic for University of Virginia residents.

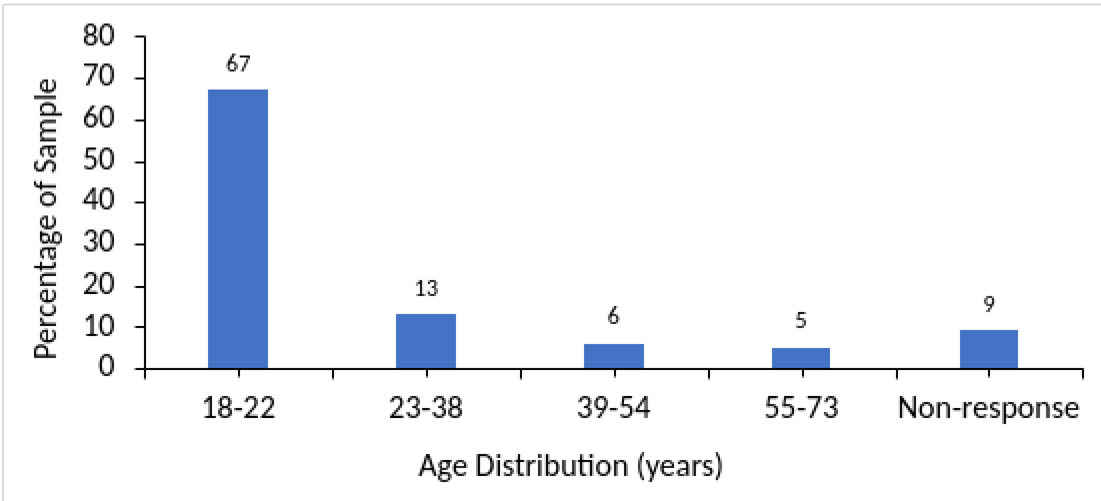

Figure 1. Age Distribution of Survey Participants

The age distribution was somewhat challenging to compare to the estimated Charlottesville population, as the United States Census Bureau divides the age groups differently than was completed for the sample. Although the United States Census Bureau included a larger age range of 18-24 (as opposed to a self identification of 18-22 years of age in this sample), the United States Census Bureau estimated that the 18-24 age group is ~24% of the Charlottesville population (United States Census Bureau, 2022). Therefore, being that the ~67% of the sample population identified as 18-22 years of age for the sample, there was an overrepresentation of the Generation Z age group in the research presented. Additionally, because there were not any individuals in the sample who identified as over the age 73 years of age, individuals from the "Silent Generation" are underrepresented in the sample, as compared to the population of Charlottesville. It is to be noted that the Charlottesville, Virginia population estimates groups individuals over the age of 65 as a single collective group, so a direct comparison to the percentage of the population over 73 cannot be determined.

When asked to identify their gender, ~50% of respondents identified as female, ~38% of respondents identified as male, ~<1% identified as non-binary/third gender, ~<1% selected "prefer not to say", and ~9% of the sample did not answer.

To the best of the researcher's knowledge, the United States Census Bureau does not release estimates for gender in Charlottesville, but data is available for the estimated percentage for biological sex of the Charlottesville population. The United States Census Bureau estimates ~49% of the Charlottesville population is male and ~51% of the Charlottesville population is female (United States Census Bureau, 2022). Therefore, the representation of female perspectives may be on par with the population proportion estimate. Comparatively, there may be an underrepresentation of male individuals in the sample, compared to the population proportion found within Charlottesville. However, because ~9% of the sample did not answer the question, there is a higher proportion of biological male or biological female respondents than reported in the gender category (in addition to those that identified as non-binary/third gender or selected "prefer not to say").

The ratio of self-identified females in the sample is higher than self-identified males. In a study conducted where researchers were determining the correlation between gender and non-response factors for online surveys, researchers found that females are more likely to participate (Smith, 2008). Although aligning with previous research, the sample could have avoided the female to male ratio bias, had the researcher completed probability sampling.

A majority of the sample identified their race as white. Over 64% of the sample identified as white, ~16% identified as Asian, ~6% identified as Black or African American, ~2% identified as American Indian/Native American or Alaska Native,~8% identified as “other”, ~<1% selected “prefer not to say”, ~<1% selected did not respond to the question (Figure 2). According to population estimates by the United States Census Bureau for 2022, the percentage of the sample for white or caucasian residents, American Indian/Native American or Alaska Native, Native Hawaiian or Other Pacific Islander, and “other” are within ~5% of each other between the sample and their estimates (Figure 2). However, compared to the population of Charlottesville, the sample from the research had an overrepresentation of Asian residents (~9%) and an underrepresentation of Black or African American residents (~12%) (U.S. Census Bureau, 2022).

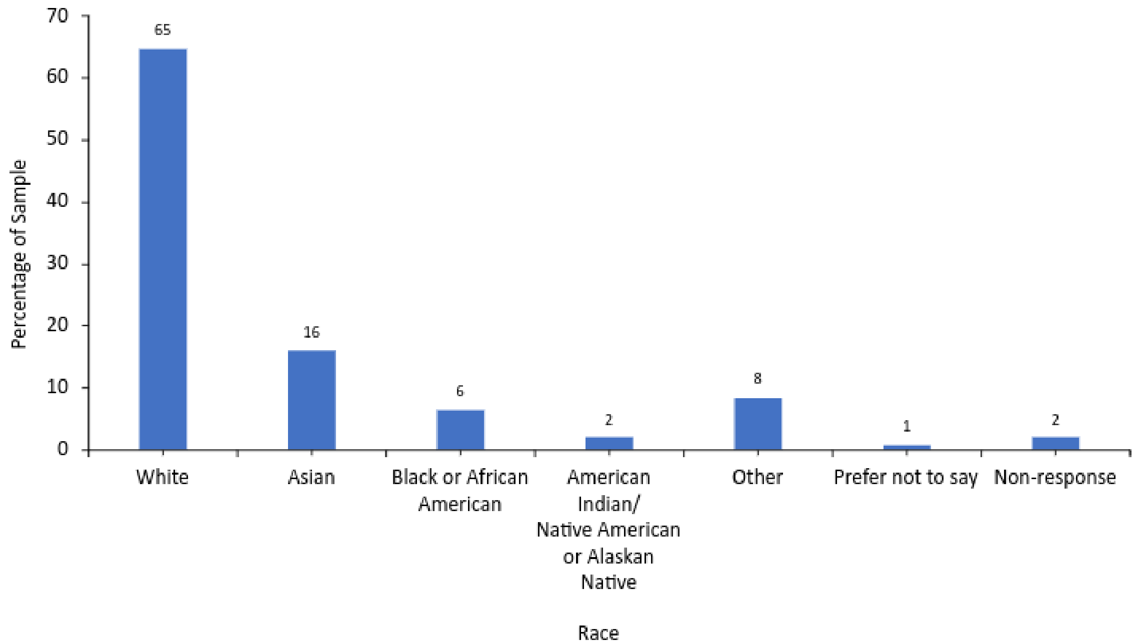

Figure 2. Percentages of Race in the Sample

As for total household income,~37% of the sample are in households that make over $150,000 annually, ~16% of the sample are in households that make between $100,000 and $149,999 annually, ~8% of the sample are in households that make between $75,000 and $99,999 annually, ~12% of the sample are in households that make between $50,000 and $74,999 annually, ~7% of the sample are in households that make between $25,000 and $49,999 annually, ~10% of the sample are in households that make less than $25,000 annually, and ~9% of the sample did not respond to the question (Figure 3).

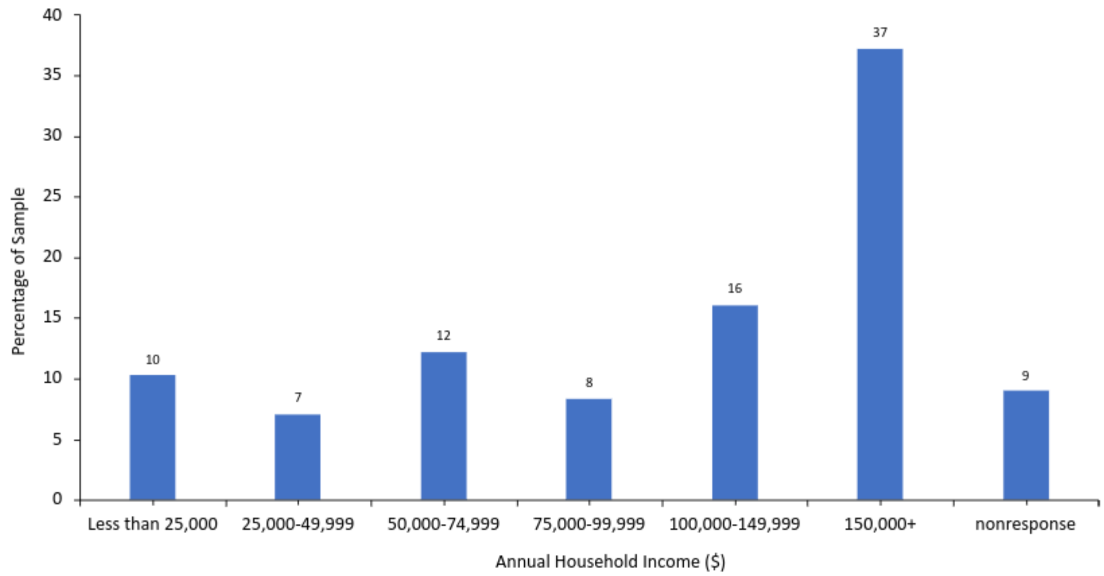

Figure 3. Total Annual Household Income for the Sample Population

Therefore, the majority of respondents were in households that make over $150,000 annually.

As compared to the estimates provided by the United States Census Bureau, although the categories slightly differ, the percentages of individuals within each category are not significantly different (Figure 4) (United States Census Bureau, 2022).

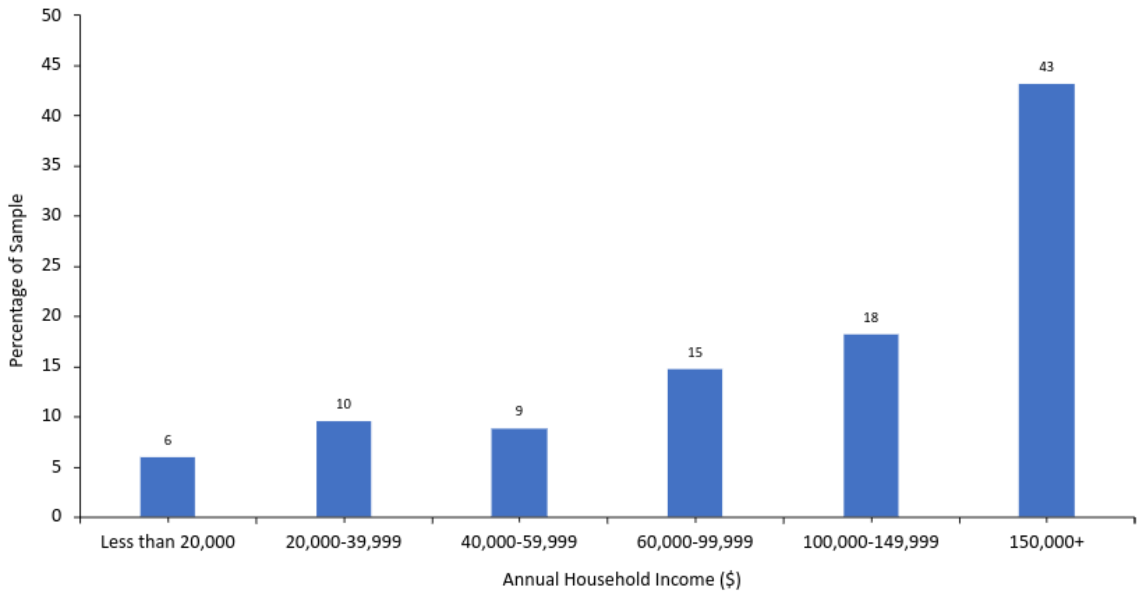

Figure 4. Total Annual Household Income for the Charlottesville Population

In another question on the survey, participants were asked to give a value including or between 0 and 7 that represented their political ideology. A value of 0 was associated with identifying as extremely liberal and a value of 7 was associated with identifying as extremely conservative. Therefore, an answer of values 0-3 represented liberal associations and an answer of values 4-7 represented conservative associations. Of the sample, ~56% identified as liberal, ~24% identified as conservative, and ~19% elected not to respond. The United States Census Bureau does not release estimates pertaining to political ideology, but being that Charlottesville is historically a more left leaning site, the data aligns with that idea.

Holistically, the sample population generally mimicked the population of Charlottesville. However, there was an overrepresentation of Generation Z individuals and those who identify their race as Asian. There was an underrepresentation of individuals who are over the age of 74 years, identified as Black or African American, or identified their gender as male within the sample.

Although the survey was collected through non-probability sampling, the remainder of the discussion assumes that the sampling was through a probability sampling method, so as to compare the population of Charlottesville to national populations or the populations of other localities. Therefore, the data is at an assumed confidence level of 95% with an 8% margin of error.

Water scarcity Perceptions

The second series of questions were about the respondents' perceptions towards water scarcity.

According to the results of the survey, ~70% of the respondents believed that access to clean water is an issue in the United States. Of the ~70%, ~33% strongly agreed. Approximately 15% of respondents disagreed and 14% of respondents did not answer the question. Being that 70% ± 8% of the Charlottesville population believed that access to clean water is an issue in the United States, this percentage is higher than the national average of ~63% derivative of the survey conducted by Grundfos (PR Newswire, 2017). According to experts, clean water accessibility remains an issue within America. Therefore, the Charlottesville population was observed to be more knowledgeable about the perception of clean water within the nation than national averages.

When asked if they believed it will be more challenging for Charlottesville to meet water needs in the next 10 to 40 years, ~64% of respondents answered yes, ~22%

answered no, and 13% did not answer. According to climate modeling scenarios for the years of 2020 and 2100 conducted by the organization “Charlottesville Acting on Climate Together” through the International Council for Local Environmental Initiatives (ICLEI), Charlottesville is expected to experience a significant increase in the number of extreme heat events and heat wave duration (n.d.). The climate models did not make a clear distinction about drought conditions, but prolonged heat waves can exacerbate drought conditions from soil moisture diminishment. Although the climate models also projected the number of extreme precipitation events and days with precipitation above 2 inches, the change was considered to be moderate, as opposed to significant like the extreme heat events. Therefore, it is likely that Charlotteville will experience a greater challenge to meet water needs in the next 10 to 40 years, agreeing with the majority of ~64% of respondents. Again, the majority of Charlottesville participants answered the question in the manner that agrees with expert opinions.

Interestingly, when asked how likely they believe that the impact of climate change will have on the water cycle to make it more difficult for Charlottesville to meet water needs in the next 10 to 40 years, ~70% of the sample believed that it will be highly likely or likely, with 29% of respondents answering specifically highly likely. Approximately 17% of the respondents answered unlikely, ~>1% answered highly unlikely, and ~12% of the sample did not respond. In this circumstance, a greater percentage of the sample agreed that water needs will be more challenging to meet. Additionally, the nonresponse rate was lower for this question than the previous question which was written similarly in format.

Comparatively, residents of Albuquerque, New Mexico (a location that presently faces water scarcity) were surveyed whether they believe the impact of climate change on the water cycle will make it more difficult for their community to meet water needs in the next 10 to 40 years. They found that ~70% of residents agreed and ~30% of residents disagreed. Therefore, approximately the same quantity of residents in a water scarce location agreed that climate change would cause an impact on their community. There were fewer respondents in the Charlottesville sample that did not believe climate change would have an effect on future community water needs (Distler & Scruggs, 2020).

Although the age distribution in the New Mexico sample was not shared, the difference in percentages between those who believed it was likely or unlikely for the question regarding how climate change will make an impact on future water supplies in Charlottesville, as opposed to the general question about future water supplies in Charlottesville, may be due to the overrepresentation of Generation Z respondents in the Charlottesville sample. Additionally, the second highest age group representation in the sample was of Millennials. According to Pew Research surveys, Generation Z and Millennials demonstrate more concern and engagement towards climate change mitigation (Tyson et. al, 2021). Therefore, differences in age distribution may be the reason for a lower percentage of Charlottesville civilians disagreeing with the impact of climate change on future water needs.

However, of the survey respondents that identified as Generation X and Boomers, (no survey respondents identified as a part of the Silent Generation), the majority of both groups agreed that climate change will make it more challenging for Charlottesville to meet water needs in the next 10 to 40 years. Combining both groups, the large majority of

~82% agreed that it will be more challenging for Charlottesville to meet water needs in the next 10 to 40 years, ~24% disagreed, and ~<6% did not answer the question. It is possible that the proportion of these generations that agreed were higher than expected because they may have been residents in Charlottesville during the drought of 2002 (roughly 21 years ago). Water context has been observed to correlate with individual conservation measures, so the results of this survey question may also demonstrate that water context may also correlate with an individual's beliefs/concern about future water supplies (Hannibal et. al, 2019).

Nonetheless, the age of an individual does not necessarily equate to length of residency, so the Generation X or Boomer individual may not have been a resident during the drought. A possible explanation for the views involving climate change and future water scarcity may be more so due to political ideology. Approximately 76% of the Generation X and Boomer population self-identified as left leaning and ~24% self identified as right leaning. Studies have shown that those who are more left leaning are more likely to be concerned about anthropogenic climate change, correlating with the survey results (McCright et. al, 2016).

Another question asked survey respondents how likely they believe the impact of climate change on the water cycle will make it more difficult for other U.S. states to meet water needs in the next 10 to 40 years. Approximately 83% of respondents answered either highly likely or likely, with ~54% answering specifically highly likely. Those that answered unlikely or highly unlikely totalled to ~5% of the sample. Nonresponse answers were ~13% of the sample. Compared to the previous question, the results show that there is a greater percentage of Charlottesville residents that believe other locations in the

United States are more likely to be affected by water shortages than Charlottesville (such as the Southwestern region of the United States), agreeing with expert opinions (Brown et al., 2019).

In terms of how knowledgeable respondents believed they were in terms of the amount of available water in Charlottesville's water supply, ~66% of respondents answered that they were either not knowledgeable enough or not at all knowledgeable, with ~28% of respondents answering specifically that they were not at all knowledgeable. Additionally, ~14% stated that they were "neutral" in terms of the knowledge of the local water supply. Approximately 6% of the sample answered that they believed they were knowledgeable and ~1% answered that they believed that they were highly knowledgeable. Approximately 13% of respondents did not answer the question. In a national water perceptions survey conducted on behalf of Grundfos, the percentage of respondents that believed they were not knowledgeable enough or not at all knowledgeable was ~35% in total (PR Newswire, 2017). Taking the results at face value, Charlottesville residents are significantly less knowledgeable about their local water supplies than the national averages. However, the results of this question may also indicate a level of willingness and curiosity by Charlottesville residents to learn more about water levels in their locality.

Another question asked respondents to select each of the conservation practices that they are currently doing at home. Because the question permitted the respondent to select multiple answers, the quantity of nonresponse values could not be calculated. The majority of respondents (111) claimed that they complete simple conservation measures like turning off the water when brushing their teeth (Figure 5). Assuming that there were not any non-response answers, the value is equivalent to ~71% of the sample. The conservation measure that was conducted the least from the population was rainwater harvesting (Figure 5).

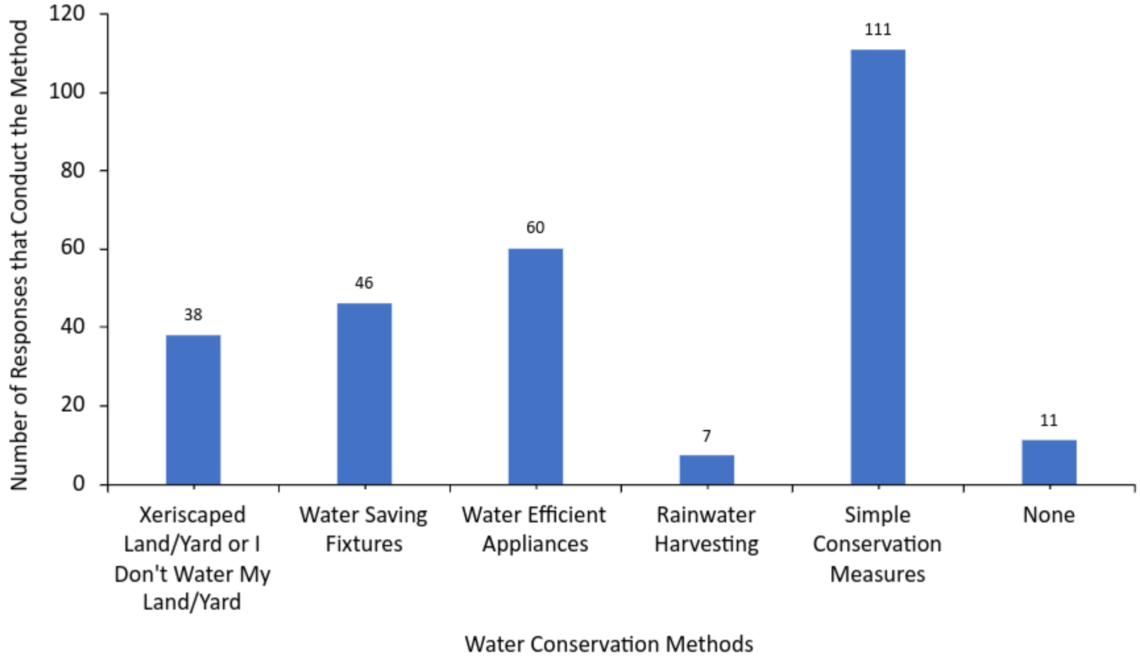

Figure 5. Water Conservation Measures Conducted by Charlottesville Sample Respondents

This question was written in a way to directly mimic a question asked to the population of Albuquerque, New Mexico. For each category, the residents of Albuquerque had a higher percentage of respondents that conducted the method (assuming there are not any non-response answers for the Charlottesville sample). However, the percentage of respondents that completed no conservation methods was higher for Albuquerque than for the Charlottesville sample (Distler & Scruggs, 2020).

This data acts as further evidence for the claim that water context impacts water conservation behaviors. In the water surplus location of Charlottesville, there are less respondents of the group completing water conservation, as compared to the water scarce location of Albuquerque. This data corresponds to the study completed in Darwin, Australia (water surplus location) and Mallee, Australia (water scarce location). Residents of Darwin also completed fewer water conservation measures ((Gilbertson et. al, 2011).

In a survey conducted in 2009, ~51% of the population were identified as water conservers (Garcia-Cuerva, 2009). Being that ~71% of the Charlottesville sample answered that they complete simple water conservation methods, the Charlottesville sample is observed to have a greater proportion of water conservers than the national average. However, this may be due to the general trend that water scarcity is increasing across the globe, considering that the national average was found in 2009. In the past, water scarcity was not as prevalent nationally, so general, widespread water context may again be the reason for an increase in water conservers in Charlottesville.

Another important trend to discuss is the lack of individuals that responded to completing water conservation activities like refraining from watering the lawn, incorporating water saving fixtures and water efficient appliances into their residences, and conducting rainwater harvesting. This could be due to the fact that there was an overrepresentation of young adults (Generation Z) who likely are not homeowners. Because the sample is likely to be representative of predominantly university students, they are most likely not home owners, and therefore cannot make modifications to their residency. Additionally, a lack of time and resources prevented the researcher from tabling at a greater number of locations to reduce coverage bias. For example, people who live in rural and remote sects of Charlottesville may be underrepresented in the dataset, as the locations for tabling and fliering may not be as accessible to them. Rural populations may be more likely to complete rainwater harvesting, based on results of a survey conducted in rural India (Ramya et. al, 2019).

For the final question of the Water Scarcity Perceptions section, participants were asked if they believe that they should pay more when evaluating their water bill, compared to their water use. Approximately 57% of respondents answered no, ~26% of respondents answered yes, and ~17% of the sample did not respond. In the national survey conducted on behalf of Grundfos, ~2% of respondents answered that they believe they should pay more when evaluating their water bill compared to their water use (PR Newswire, 2017). This data provides supporting evidence that Charlottesville residents may be more open to water restrictions and water limits than the national averages. Applying the idea of water context, both Generation X and Boomers from the sample had higher percentages of individuals answering that they believe that they should pay more when evaluating their water bill. A possible reason for this may be because they were in Charlottesville when the 2002 drought occurred (they have previously faced water scarcity).

Overall, Charlottesville sample respondents were considered knowledgeable about water scarcity. This was determined based on the fact that for all but one question, the majority of respondents either agreed with expert opinions on water scarcity facts or the respondents ranked higher than the national averages for water scarcity perceptions. The only question that Charlottesville was considered less knowledgeable regarding water scarcity perceptions was the question where Charlottesville residents were asked to identify how knowledgeable they were about local water levels. This contradicts the hypothesis that Charlottesville residents may be less knowledgeable about water scarcity compared to the national averages. However, when the Charlottesville population was compared to the water conservation measures of water scarce Albuquerque, New Mexico, Charlottesville residents were found to be less water conscious. This supports the hypothesis that Charlottesville residents would be less likely to be completing water conservation practices, as opposed to their water scarce counterparts.

Solutions

For the prevailing issue of water scarcity, there are a number of proposed solutions in terms of mitigation. According to a book written by a professor who teaches Water Sustainability at the University of Virginia and previously served as the Director of the Global Water Program of The Nature Conservancy, the 6 general solutions for combating water scarcity include desalination, water reuse, water importation, water storage, watershed management and water conservation (Richter, 2014). The predominant solutions discussed in this section involve increased **wastewater reuse, individual conservation efforts, education, institutionalized water resource management practices, and green infrastructure.** The next set of questions asked the survey participants about their perceptions towards water scarcity solutions. There were 14 questions in this section.

Wastewater Reuse

Wastewater reuse, also known as water recycling or water reclamation minimizes water consumption. Wastewater includes sewage water as well as greywater. Greywater reuse pertains to reuse of sink water, shower water, and laundry water.

Planned water recycling is conducted through water treatment plants. Oftentimes, recycled water is used for the purposes of watering agricultural fields, public parks, and golf courses (US EPA, 2017). The water is also used for cooling down electric plants or oil refineries, as well as for the commercial manufacturing of products like paper and construction materials (US EPA, 2017). Overall, most planned water recycling programs do not reuse the water for drinking purposes.

Although uncommon, there are some cases where water recycling is used for the purposes of potable water through indirect methods. For example, recycled water can be used to recharge groundwater aquifers (which also protects against saltwater intrusion in coastal areas) or to refill surface water reservoirs' both bodies of water that municipalities use as sources of potable water. In Fairfax, Virginia, the Occoquan Sewage Authority releases their recycled water into a stream adjacent to the the potable water source of the Occoquan Reservoir (US EPA, 2017). This is the only site in Virginia that conducts indirect potable water reuse. There are not any sites in Virginia that conduct direct water reuse.

Wastewater reuse beneficially serves the environment and the economy. Water recycling can reduce a community's reliance on water from sensitive aquatic ecosystems, paired with a reduction of wastewater discharge that may pollute waterways (US EPA, 2017). Additionally, some facilities in the United States turn wastewater byproducts into fertilizers. The recycled water itself can also be injected to enrich sensitive ecosystems, in the case that the water levels are low at the source. Finally, water reclamation can reduce energy burdens associated with water extraction, treatment, and transport (especially in regards to desalination practices) (US EPA, 2017). When water recycling is adjacent to those that need it, the energy cost of extraction and transport are greatly reduced (US EPA, 2017).

Water reclamation is divided into two categories: direct potable water reuse and indirect potable water reuse. Direct potable water reuse (DPR) is when water is treated in a water treatment plant without the use of an environmental buffer beforehand. However, the negative stigma surrounding DPR remains a hurdle, as there are a select number of sites that complete this form of reuse (Haddad et. al, 2009). Comparatively, a more common method of water reuse is called planned indirect potable water reuse (IPR). This is when environmental buffers like rivers, lakes, and reservoirs are used to naturally filter and purify water before entering drinking water treatment plants. The solution of IPR may be considered more favorable because it is generally more inexpensive than direct potable water reuse and requires less electricity generation (Rodriguez et al., 2009). The city of Charlottesville does not deploy either technique for potable water reuse, so the survey results were attained to understand the perception towards these possible methods of mitigating water scarcity.

According to the survey results, ~62% of participants were aware of the concept of purifying wastewater to be reused for drinking water, ~21% of participants were unaware, and ~17% of the sample did not respond to the question. Considering that Charlottesville does not have wastewater reuse facilities, having the majority of respondents being aware of the concept provides further evidence that the Charlottesville population may be knowledgeable of water scarcity best practices.

The following set of questions explained the differences between direct potable water reuse and indirect potable water reuse to the survey participant. Then, the survey respondents were prompted to answer how willing they were to drink from the source of potable water (Figure 6 & Figure 7).

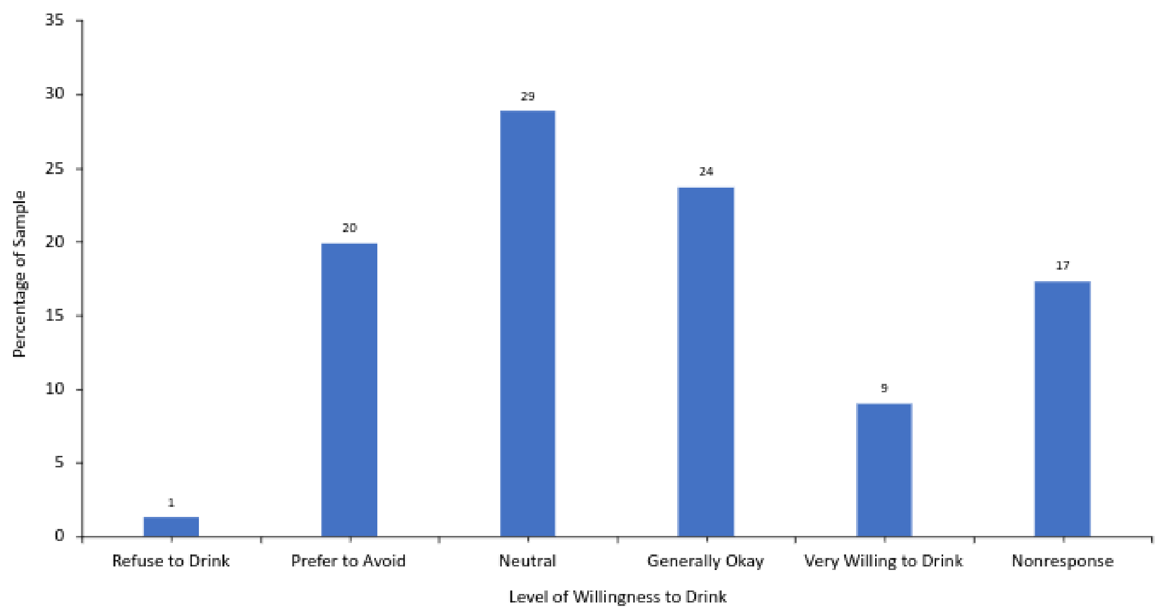

Figure 6. Level of Willingness to Drink Direct Potable Water Reuse by Charlottesville Respondents

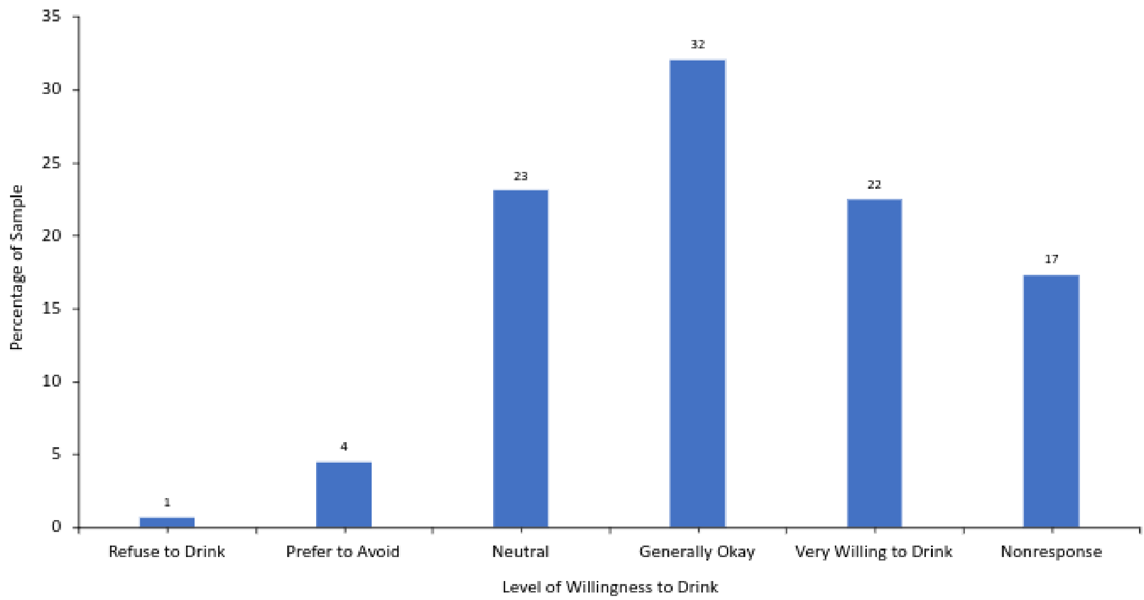

Figure 7. Level of Willingness to Drink Indirect Potable Water Reuse by Charlottesville Respondents

As observed by the figures, Charlottesville respondents seem to be more willing to drink indirect potable water reuse, as opposed to direct potable water reuse (Figure 5 & Figure 6). This is likely due to the negative stigma surrounding recycled water. In the national survey conducted on behalf of SUEZ Water Technology Solutions, ~70% of the sample either agreed or strongly agreed that there is a stigma associated with recycled water, which these data results support (Veolia, 2020). When a similar question was asked to residents of Albuquerque, New Mexico, for both indirect and direct potable water reuse, the majority of participants responded that the methods were “generally okay” (Distler & Scruggs, 2020). This differs from the Charlottesville sample, as direct water reuse had a greater proportion of “neutral” willingness to drink, as opposed to “generally okay”. This may be due to the fact that Charlottesville is presently water abundant, as opposed to Albuquerque.

Then, survey respondents were asked to directly compare their willingness to drink indirect potable water reuse and direct potable water reuse (Figure 7). Approximately 40% of respondents stated that both types of reuse are equally acceptable, ~36% of respondents were more willing to drink indirect drinking water reuse than direct drinking water reuse, and ~4% were more willing to accept direct drinking water reuse (Figure 7).

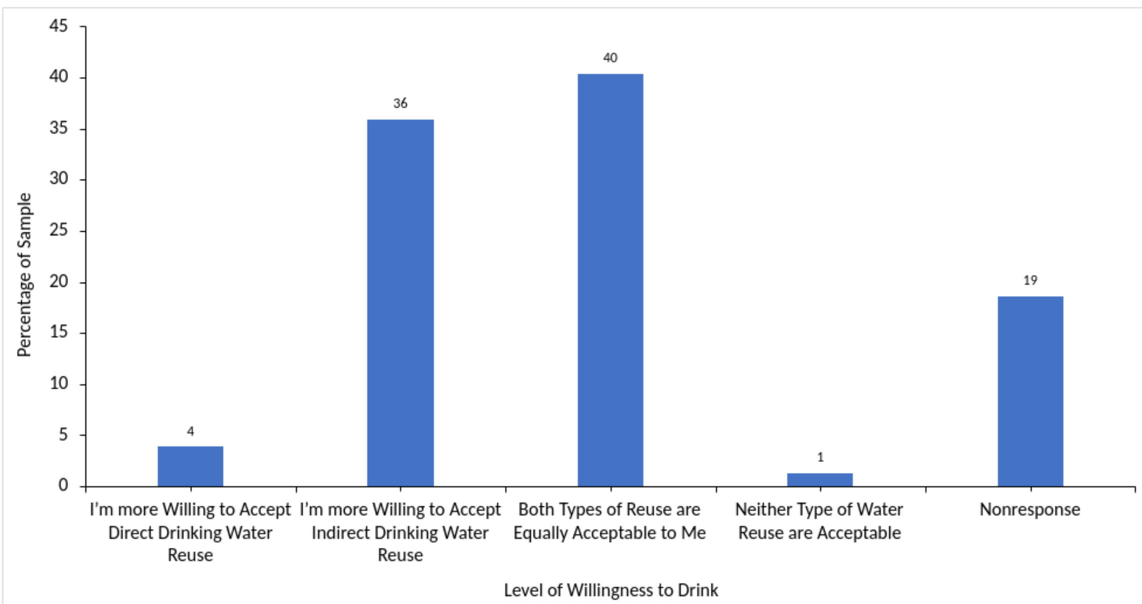

Figure 7. Comparative Level of Willingness to Drink Indirect Versus Direct Potable Water Reuse by Charlottesville Respondents

Therefore, indirect water reuse may be a satisfactory solution to reduce water scarcity in Charlottesville, although more people believe that both methods are equally acceptable.

Charlottesville Water Conservation and Education

Education about water conservation and importance is another possible solution to cause water consumption to decrease in localities.

Another question prompted survey participants to answer if they believed that more Charlottesville residents should be educated on how to decrease water shortages. Of the sample, ~78% responded yes, ~4% responded no, and ~18% did not answer the question. This data provides supporting evidence that there is a possible desire, curiosity, and need to learn more about water conservation methods, specifically within Charlottesville, Virginia.

Similarly, when asked if they think that more action needs to be taken in their community to conserve water, ~73% of respondents answered yes, ~10% of respondents answered no, and ~18% of respondents did not answer. Again, with a majority agreeing to taking more action, there seems to be an openness for community action. When this survey question was asked on a national scale, ~74% said yes, similar to the percentage attained in this survey research (PR Newswire, 2017).

When asked if respondents knew that Charlottesville Water offers rain barrel rebates, efficient water consumption toilet rebates, and free water conservation kits (including water efficient faucet aerators, shower-heads, and toilet leak detection tablets), ~12% of respondents answered yes, ~71% of respondents answered no, and ~18% of respondents did not answer. Therefore, the majority of respondents are unaware of water conservation offerings. A method by which to increase water conservation in Charlottesville may be through better marketing of the current water conservation incentive offerings.

Approximately 6% of the sample answered that they participated in the aforementioned offerings from Charlottesville Water, ~65% of respondents claimed that they had not, and ~29% of respondents did not answer. Comparing these results to the previous results, approximately half of the respondents that claimed that they were aware of the offerings participated in them. Therefore, these results may signify that greater awareness may equate to a greater percentage of Charlottesville Water incentives.

Building upon the last question, the survey prompted those that answered they had not participated in the offerings from Charlottesville Water to select reasons why they elected not to participate. Approximately 88% of respondents claimed it was because they were unaware of the offerings, ~2% of respondents claimed that it was because it was inconvenient to them, ~4% of respondents claimed that they did not have a desire to participate, and ~5% of respondents selected the answer choice of “other” (Figure 8).

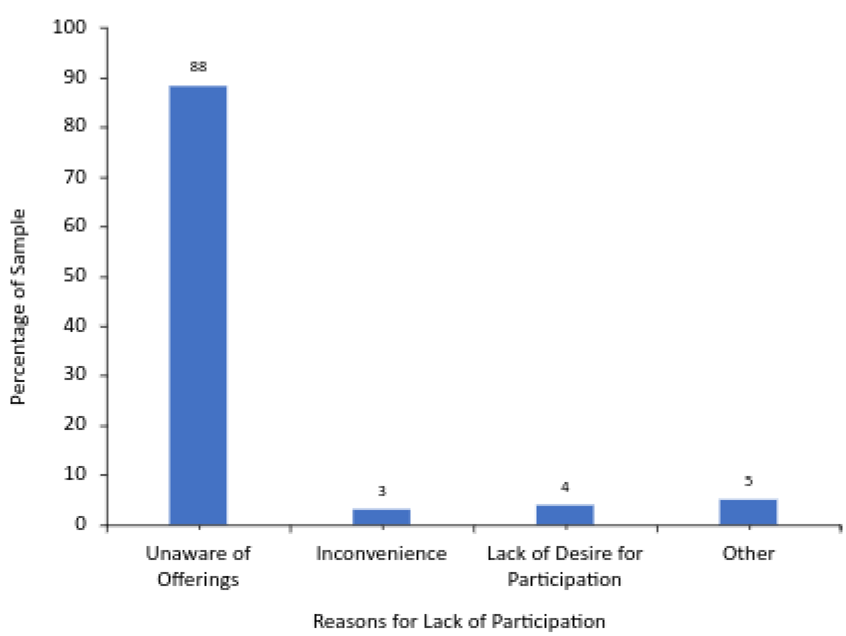

Figure 8. Reasons for Charlottesville Residents Lack of Participatio

Each participant that selected the "other" option left responses that involved the inability to modify their unit, as they do not own the property that they live in. Again, this is most likely due to the overrepresentation of younger generations in the sample. These survey results support the need for increased awareness of water conservation incentives in Charlottesville, Virginia.

The last question of the survey asked participants how they believe that water scarcity can be solved in Charlottesville and what they think are the best solutions to reducing water shortages. The question prompted participants to answer in a short answer format. The short answers were aggregated based on similar answers. Of the answers that provided solutions, 30 mentioned increased education, 12 mentioned policy reform, 8 discussed improved infrastructure, 8 mentioned water conservation measures, and 8 mentioned water treatment and reuse (Figure 9).

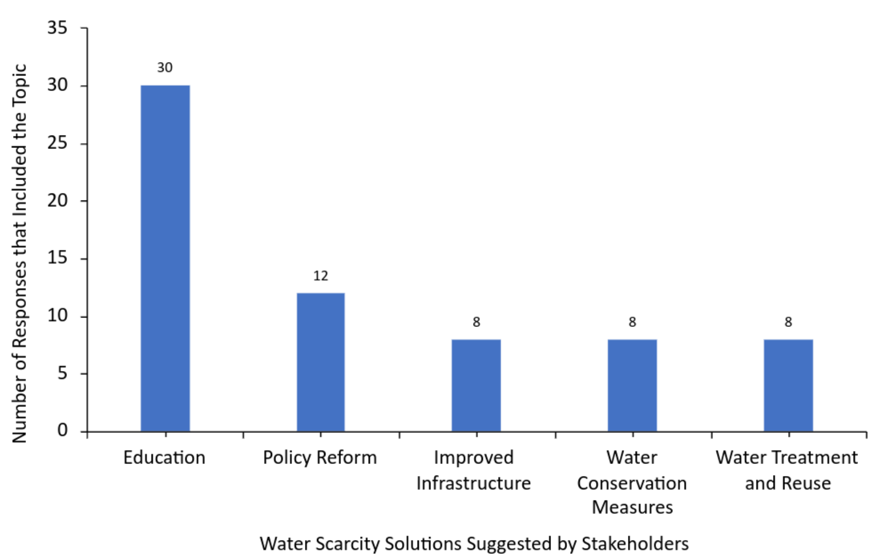

Figure 9. Water Scarcity Solutions Suggested by the Respondents with the Corresponding Number of Responses that Included the Topic

For a more clear understanding of the suggested solutions by Charlottesville residents, the survey responses were aggregated and summarized (Table 1). Although most of the responses could be applied to most general locations, there were some responses that pertain more specifically to Charlottesville. For example, one response suggested dredging South Fork Reservoir. Dredging involves the removal of sediments from the bed of a water body (Bray, 2008). Although dredging can improve water quality by removing the sediments that may possibly contain debris, the method may also cause negative impacts to the environment (Bray, 2008). For example, changing the morphology and the water quality of the water body may cause habitat loss/destruction, affecting the aquatic wildlife in the area (Bray, 2008). Additionally, considering the high cost of dredging paired with the unpredictability of impact at the site, this solution may not be optimal for Charlottesville, Virginia.

Table 1. Aggregated Stakeholder Short Answer Solutions Sorted by Topic

Education	Policy Reform	Improved Infrastructure	Water Conservation Measures	Water Reuse and Purification
Educate residents where water comes from	Tax relief incentives for water conservation measures	Increase water efficient appliances in new buildings	Ration water use on a city wide scale	Wastewater and greywater treatment and reuse
Educate residents of at home water conservation measures and their impact on local water levels	Increase access to water conservation measures like rain barrels for local individuals	Dredge South Fork Reservoir	Simple individual water conservation methods	Desalination
Educate residents on water conservation incentives/subsidies in Charlottesville	Ban or place premium prices on non-agricultural irrigation for golf courses, lawns, etc.	Impose stricter limits on silt fencing for new construction	Planting native flowers on property (as opposed to plants that require more watering or care)	
Educate residents about level of individual water use and how it affects the local water levels	Plan for drought scenarios at government and university levels	Require water permeability in new parking lots to slow surface runoff		
Educate residents on how water scarcity affects people (humanize the issue)	Limit the amount of water for industrial and commercial purposes and for larger institutions like the University of Virginia			
Educate residents about environmental impacts of runaway population growth	Enforce real estate brokers to pay for water infrastructure improvements			
Include water conservation in the school curriculum	Increase the price of water progressively			
Increased marketing of information for greater accessibility	Increase rates for each block of consumption above a minimum amount per household			
Promote and inform local, corporate institutions about water conservation				

Other infrastructure improvements may be more suitable for the city of Charlottesville. Green water systems infrastructure is another way to incorporate water conservation habits into daily life. This is when natural systems are implemented to manage stormwater. Practices may include incorporating rainwater harvesting practices into city buildings, increasing the number of trees and plants in urban settings for greater water filtration, and installing permeable pavements. These practices act as a superb additive to the other mitigative practices aforementioned.

In Charlottesville, green water systems infrastructure is common. Specifically, at the University of Virginia, water conservation is a high priority. The University has completed stream daylighting for Meadow Creek, incorporated cisterns that capture rainwater for landscaping, and purposefully planted vegetation to filter the rainwater for further percolation into groundwater systems (The Office of the Architect, UVA, n.d.) . They also have a water condensation capture system that collects and disseminates the condensation from air handlers, recovering 2 million gallons of water (The Office of the Architect, UVA, n.d.).

Errors and Limitations

The predominant limitations to this project include time and resources. Had the researcher had more time and resources to retrieve survey responses, the survey results could have been more statistically significant due to a greater sample size. Additionally, the researcher could have utilized a probability sampling method so as to best mimic the Charlottesville population. For example, with increased time and resources, the researcher could have distributed through the surveys via mail to Charlottesville residents.

Unfortunately, sampling error did occur, despite the measures the primary researcher took to ensure that each survey respondent was a Charlottesville resident. Some respondents identified themselves as residents of other localities, in the short answer survey question.

Nonresponse error posed a great hurdle to the research results, although the researcher attempted to reduce nonresponse error through multiple techniques, as discussed in the methods section. The researcher received over 150 survey responses to achieve an assumed 95% confidence level with an 8% margin of error, but the researcher did not anticipate some survey questions to have over an 18% nonresponse error.

Conclusion

Overall, the hypothesis that Charlottesville residents may be less knowledgeable about water scarcity compared to the national averages was not supported. Additionally, the hypothesis that Charlottesville residents would be less likely to be completing water conservation practices, as opposed to their water scarce counterparts, was supported. Being that the Charlottesville residents from the sample demonstrated curiosity in learning more about water conservation, the community may benefit from increased water conservation education programs. Paired with the fact that a large majority of individuals that were not participating in the offerings was due to unawareness, increased marketing towards water conservation incentive programs should be conducted to reduce the potential of future water scarcity. The survey results suggest that Charlottesville is water abundant due to proper local institutionalized water management, paired with conservation measures by Charlottesville residents.

Future Studies

Holistically, future research for Charlottesville water scarcity perceptions should be completed over longer periods of time to increase the number of survey responses, in addition to using probability sampling methods.

To expand this research, one may survey a population that is representative of home-owners in Charlottesville, rather than Charlottesville renters. Many conservation methods (such as installing water efficient appliances or watering lawns) may only be completed by homeowners and property managers. This could be completed by mailing the survey to non-rented homes in Charlottesville. Information about the water conservation methods of Charlottesville homeowners may be of particular interest.

Additionally, the same survey from this research could be completed through probability sampling, if the time and resources allows, to create a lower margin of error. Pearson's Chi Square tests of independence can be performed to test relationships between variables such as those asked in the "demographics" section of the survey.

One could complete a survey of simple random sampling of the University of Virginia community where the researcher randomly selects school email addresses to distribute the survey to, out of a list of all current University of Virginia students. Then, the researcher could initiate follow-up email correspondence with those that did not take the survey, to decrease nonresponse bias. Stratified random sampling could also be completed to increase statistical significance, time allowing.

Finally, this survey could be redistributed after water conservation programs have been initiated to see if the number of water conservation measures has increased or if stigma towards direct or indirect potable water reuse has decreased over time.

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Appendix

Survey

Informed Consent Agreement- 2 Questions

Q1. Informed Consent Agreement
Study Title: Perceptions of Water Scarcity in Charlottesville, Virginia
Protocol #: 6188 Please read this consent agreement carefully before you decide to participate in the study.
Purpose of the research study: The research is being conducted by a student at the University of Virginia for undergraduate capstone research. The purpose of the study is to observe reactions, perceptions, knowledge levels, and solutions for water scarcity by Charlottesville residents.
What you will do in the study: You will take an anonymous survey about water scarcity and its potential solutions, either on paper or electronically on Qualtrics.
Time required: The study will require approximately 10 minutes of your time.
Risks: There are no anticipated risks in this study.
Benefits: There are no direct benefits to you for participating in this research study. The study may help us understand best management practices to mitigate global water shortages and see the level of knowledge by those who are not affected by water scarcity.
Confidentiality: The information that you give in the study will be anonymous. Your name and other information that could be used to identify you will not be collected or linked to the data. Voluntary participation: Your participation in the study is completely voluntary.
Right to withdraw from the study: You have the right to withdraw from the study at any time without penalty. However, once your responses are submitted there is no way for them to be deleted since this study is anonymous.
How to withdraw from the study: If you want to withdraw from the study, simply close the survey at any time before submission or do not turn in the paper survey.
There is no penalty for withdrawing. Because the data are not connected to your identity, you cannot withdraw after you submit your data. Payment: You will receive no payment for participating in the study. Using data beyond this study: The researcher would like to make the information collected in this study available to other researchers after the study is completed. The researcher will remove any identifying information (such as your name, contact information, etc.) connected to the information you provide. The researcher will share all of the information collected in this study (not just your individual file) with other researchers for future research studies, including but not limited to those involving water scarcity. The researcher will make the information available on a public website such as

LinkedIn. Researchers of future studies will not ask your permission for each new study. The other researcher will not have access to your name and other information that could potentially identify you nor will they attempt to identify you.

Please contact the researchers on the study team listed below to:
- Obtain more information or ask a question about the study.
- Report an illness, injury, or other problem.
- Leave the study before it is finished.

Skylar Jackman- Principal Investigator Environmental Sciences Department, 291 McCormick Rd, Charlottesville, VA 22903 University of Virginia, Charlottesville, VA 22903. (540)498-3155
saj3hbc@virginia.edu

Brian Richter- Faculty Advisor Environmental Sciences Department, 291 McCormick Rd, Charlottesville, VA 22903 University of Virginia, Charlottesville, VA 22903. (434)996-0147
bdr2a@virginia.edu

You may also report a concern about a study or ask questions about your rights as a research subject by contacting the Institutional Review Board listed below.

Tonya R. Moon, Ph.D. Chair, Institutional Review Board for the Social and Behavioral Sciences One Morton Dr Suite 400 University of Virginia, P.O. Box 800392
Charlottesville, VA 22908-0392
Telephone: (434) 924-5999
Email: irbsbshelp@virginia.edu
Website: https://research.virginia.edu/irb-sbs
Website for Research Participants: https://research.virginia.edu/research-participants

UVA IRB-SBS # 6188

You may print or save a copy of this consent for your records. For those using a paper version of the survey, you will receive a copy of this consent for your records

Please check this box to indicate that you are 18 or older, that you have read the above information, and that you are willing to take part in the study.

.

Demographics- 6 Questions

Q2. Select your age range.

18-22

23-38

39-54

55-73

74+

Q3. How do you describe yourself?

Male

Female

Non-binary / third gender

Prefer to self-describe

Prefer not to say

Q4. Choose one or more races that you consider yourself to be

White or Caucasian

Black or African American

American Indian/Native American or Alaska Native

Asian

Native Hawaiian or Other Pacific Islander

Other

Prefer not to say

Q5. What is the highest level of education you have completed?

Some high school or less

High school diploma or GED

Some college, but no degree

Associates or technical degree

Bachelor's degree

Graduate or professional degree (MA, MS, MBA, PhD, JD, MD, DDS etc.)

Prefer not to say

Q6. What was your total household income before taxes during the past 12 months? If you are a student, report your estimated family income.

Less than 25,000

25,000-49,999

50,000-74,999

75,000-99,999

100,000-149,999

150,000+

Q7. Here is a 7-point scale on which the political views that people might hold are arranged from extremely liberal (left) to extremely conservative (right). Where would you place yourself on this scale?

	0	1	2	3	4	5	6	7
Political Ideology								

Water Shortage Perceptions

Q8. Do you believe that access to clean water is an issue in the United States?

Strongly agree

Agree

Disagree

Strongly disagree

Q9. Do you believe it will be more challenging for Charlottesville to meet water needs in the next 10 to 40 years?

Yes

No

Q10. How likely do you believe the impact of climate change on the water cycle will make it more difficult for Charlottesville to meet water needs in the next 10 to 40 years?

Highly likely

Likely

Unlikely

Highly unlikely

Q11. How likely do you believe the impact of climate change on the water cycle will make it more difficult for other U.S. states to meet water needs in the next 10 to 40 years?

Highly likely

Likely

Unlikely

Highly unlikely

Q12. Rate your level of concern with local drinking water quality.

Not at all concerned

Slightly concerned

Moderately concerned

Very concerned

Extremely concerned

Q13. Are you already being affected by water shortages?

Yes

No

Q14. In your opinion, do you think water is a limited resource in your local area?

Yes

No

I don't know

Q15. How knowledgeable do you think you are in terms of the amount of available water in Charlottesville's local water supply?

Highly knowledgeable

Knowledgeable

Neutral

Not knowledgeable enough

Not at all knowledgeable

Solutions

Q16. Which of the following are you currently doing at home? Check all that apply.

Xeriscaped land/yard or I don't water my land/yard

Water saving fixtures (e.g., faucets, toilets)

Water efficient appliances (e.g., dishwasher, washing machine)

Rainwater harvesting (e.g., rain barrel)

Simple conservation measures (e.g., turning off water when brushing teeth)

None

Q17. Do you believe that you should pay more when evaluating your water bill, as compared to your water use?

Yes

No

Q18. Are you aware of the concept of purifying wastewater and reusing it for drinking water?

yes

no

Q19. Direct water reuse is when water is treated in a water treatment plant without the use of an environmental buffer beforehand. How WILLING would you be to drink direct potable reuse?

Refuse to drink

Prefer to avoid

Neutral

Generally okay

Very willing to drink

Q20. Indirect water reuse is when environmental buffers like rivers, lakes, and reservoirs are used to naturally filter your water before entering drinking water treatment plants. How WILLING would you be to drink indirect potable reuse?

Refuse to drink

Prefer to avoid

Neutral

Generally ok

Very willing to drink

Q21. Which of the following statements do you most agree?

I'm more willing to accept Direct Drinking Water Reuse

I'm more willing to accept Indirect Drinking Water Reuse

Both types of reuse are equally acceptable to me

Neither type of water reuse are acceptable

Q22. For what reasons would you be WILLING to drink indirect potable reused water in your community?

Water shortage, drought, or limited water supply

Reduces waste; efficient use of resources

Purified water is safe to drink and is safely consumed in other US cities

I trust the purification technologies

The water passes through the environment before it is treated and used again

Not applicable- i would not be willing to drink the water

Other

Q23. For what reasons would you be WILLING to drink DIRECT potable reused water in your community?

Water shortage, drought, or limited water supply

Reduces waste; efficient use of resources

Purified water is safe to drink and is safely consumed in other US cities

I trust the purification technologies

Not applicable- i would not be willing to drink the water

Other

Q24. For what reasons would you NOT be willing to drink INDIRECT potable reuse water in your community?

I'm not confident the water is safe; health concerns

No concerns

I don't trust the government or water utility

I would expect a bad taste/smell or discoloration of the water

I don't trust the purification terchnologies

Other

Q25. For what reasons would you NOT be willing to drink DIRECTpotable reuse water in your community?

I'm not confident the water is safe; health concerns

No concerns

I don't trust the government or water utility

I would expect a bad taste/smell or discoloration of the water

I don't trust the purification terchnologies

Other

Management & Conservation

Q26. Do you believe that more Charlottesville residents should be educated on how to decrease water shortages?

Yes

No

Q27. Do you think that more action needs to be taken in your community to conserve water?

Yes

No

Q28. Did you know that Charlottesville Water offers rain barrel rebates, efficient water consumption toilet rebates, and free water conservation kits (include water efficient faucet aerators, shower-heads, and toilet leak detection tablets)?

Yes

No

Q29. Have you participated in any of the aforementioned water conservation incentives?

Yes

No

Q30. If you have not participated in them, why not?

Was not aware of them

Inconvenient (Do not want to allot time to complete the activity)

Do not have a desire in participation

Other

Q31. Now that you are aware of the water conservation programs, how likely are you to participate in at least one of them?

Highly likely

Likely

Neutral

Unlikely

Highly unlikely

Q32. How do you think water scarcity can be solved in Charlottesville? What do you think the best solutions are to reducing water shortages? Leave any additional thoughts or comments below.

Supplemental Data

Table 2. Education Level Distribution of Charlottesville Sample Population

Education Level	Percentage of Sample (%)
Some college, but no degree	50
Bachelor's Degree	18
High School Diploma or GED	11
Associates or Technical degree	4
Non-response	9

Table 3. Level of Concern with Local Drinking Water by Charlottesville Sample Population

Level of Concern	Percentage of Sample (%)
Not at all Concerned	29
Slightly Concerned	29
Moderately Concerned	21
Very Concerned	6
Extremely Concerned	2
Nonresponse	13

Table 4. Impact of Water Shortages by Charlottesville Sample Population- An answer of "yes" signifies that they are already being impacted and an answer of "no" means that they are not.

Impacted by Water Shortages	Percentage of Sample (%)
Yes	82
No	5
Nonresponse	13

Table 5. Water Resources in Charlottesville- An answer of "yes" indicates that the respondent believes that water is a limited resource in Charlottesville and an answer of "no" indicates that the respondent does not.

Whether Water is a Limited Resource	Percentage of Sample (%)
Yes	13
No	50
Nonresponse	37

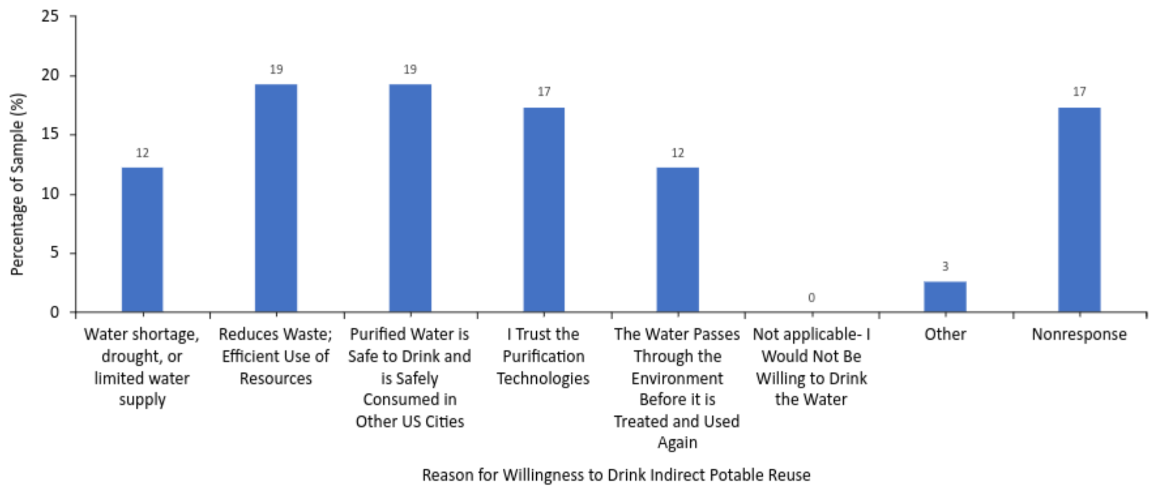

Figure 10. Reasons for Willingness to Drink Indirect Potable Reuse Water by the Charlottesville Sample Population- survey participants could select the predominant reason why they would be willing to drink indirect potable reuse water.

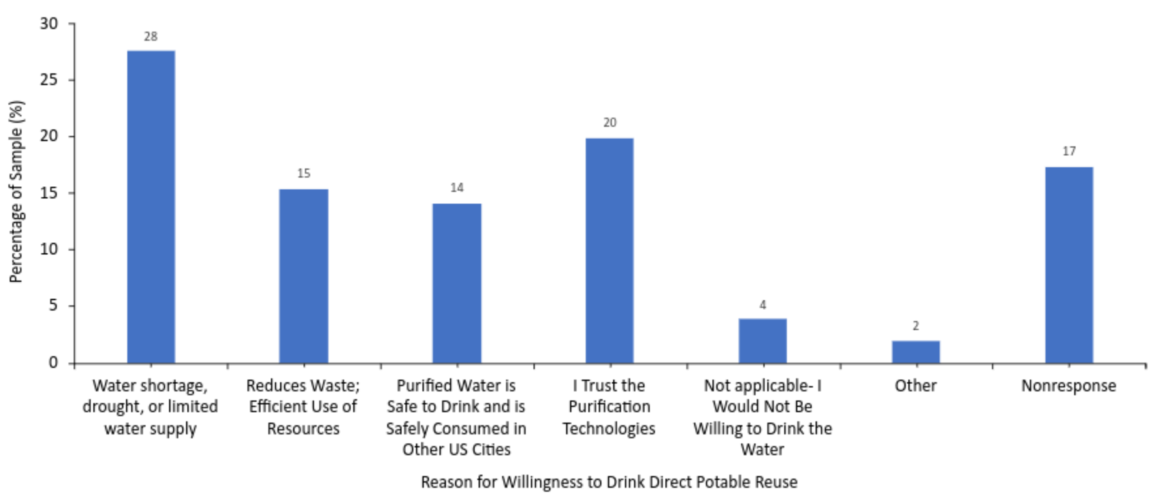

Figure 11. Reasons for Willingness to Drink Direct Potable Reuse Water by the Charlottesville Sample Population- survey participants could select the predominant reason why they would be willing to drink direct potable reuse water.

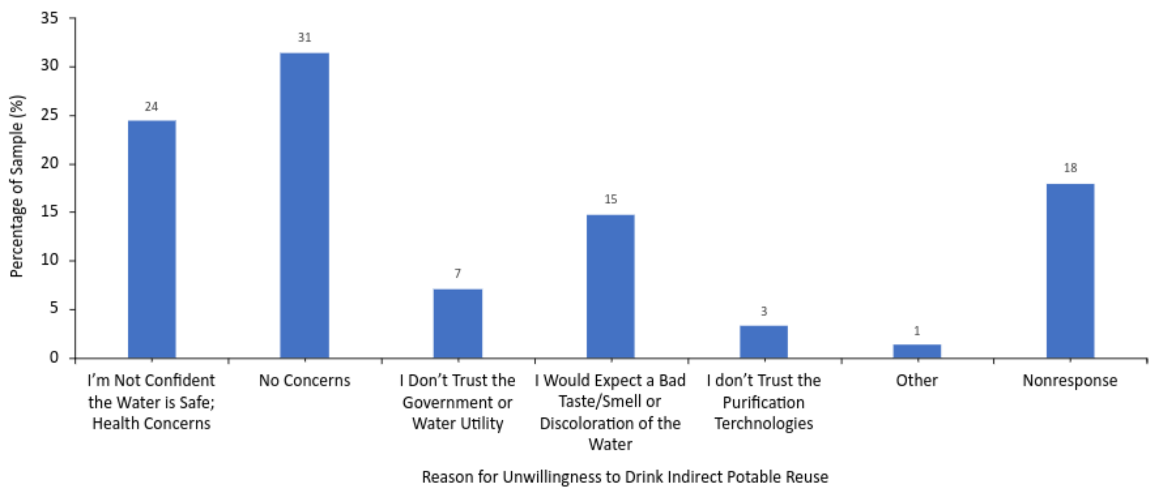

Figure 12. Reasons for Unwillingness to Drink Direct Potable Reuse Water by the Charlottesville Sample Population- survey participants could select the predominant reason why they would not be willing to drink indirect potable reuse water.

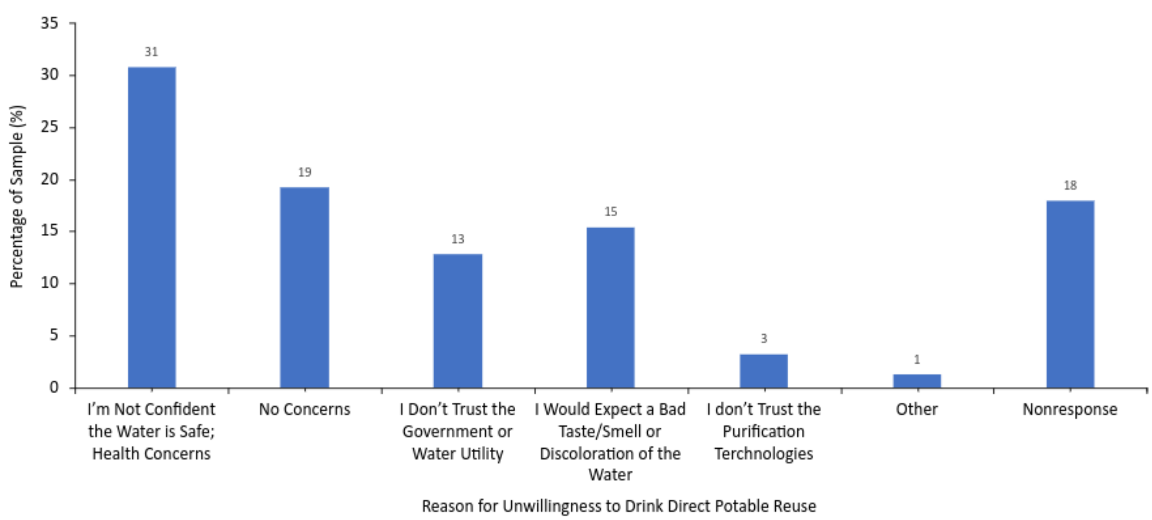

Figure 13. Reasons for Unwillingness to Drink Direct Potable Reuse Water by the Charlottesville Sample Population- survey participants could select the predominant reason why they would not be willing to drink direct potable reuse water.