Public Water Supply Expansion, Safe Water Access, and Health in Rural Appalachia: A 30-year Retrospective Analysis of the Coalfield Water Development Fund's Impacts in Southwest Virginia

Technical Report

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Executive Summary

Safe and affordable drinking water is necessary for human health, development, and dignity. Consumption of unsafe drinking water is associated with a substantial burden of disease globally. In the US, where ~1.8 million people in rural areas lack safe drinking water, a recent nationwide analysis identified Central Appalachia as one of the regions with the highest rates of incomplete plumbing and drinking water violations. However, our understanding of exposures to drinking water contaminants and associated impacts on health in Central Appalachia and in the coalfield counties of southwest Virginia remains limited by a lack of data.

The Coalfield Water Development Fund (CWDF), a non-profit established in 1996, has provided >$10 million in grants to help close funding gaps and increase the affordability and accessibility of public water supply in low income and rural communities in southwest Virginia. We used detailed project and expenditure records from the CWDF, as well as US Census, US Environmental Protection Agency (EPA), and other data sources to characterize, quantify, and assess CWDF's funding support efforts over the last ~30 years in the coalfield counties of far southwest Virginia (Buchanan, Dickenson, Lee, Russell, Scott, Tazewell, and Wise Counties, and the city of Norton), and associated county-level estimates of the population served by utilities over this time, as well as the estimated burden of disease averted for those households who transitioned from private (well water, spring water) to public (utility) water supply over this time period. For the latter, we conducted a Quantitative Microbial Risk Assessment (QMRA) based on CWDF project data, publicly available demographic data, and pathogen specific dose-response and other data and estimates from our prior studies and other sources to estimate health impacts for populations who gained access to utility-supplied water via CWDF-supported projects.

Among other findings for the region, our analyses revealed that while median incomes have gradually increased over the last ~30 years in these counties, after adjusting for inflation median income growth was only slightly positive over the time period assessed, and that, overall, poverty rates in Virginia's coalfield counties increased over the time period covered. US Census data also show that the population declined across all counties at an approximate average rate of -13% from 2000-2020 (while the state-wide and national populations increased). With regard to CWDF investments, our analyses show that: from 1996 to 2023, CWDF invested $10,939,007 in water supply expansion and infrastructure maintenance/upgrade projects that provided new utility water supply for 12,388 people; CWDF's investments in water supply in the region have increased year-over-year, even after adjusting for inflation; in Buchanan County, CWDF-supported projects have expanded access for ~27% of the entire county population (and ~10% in Dickenson); and an estimated ~24,900 infections from waterborne pathogens were likely averted thanks to the expansion of CWDF-supported utility-supply water expansion in the region (vs. continued consumption of unregulated well and spring water).

The report concludes with a discussion of other related factors and methodological limitations. Overall, our analyses help quantify the substantial beneficial impacts CWDF-supported utility water supply expansion and maintenance/upgrade projects have provided for populations living in Virginia's coalfield counties over the last ~30 years and, as we conclude, there are many other accrued benefits to health and wellbeing for residents of these counties that are beyond the scope of the analyses and results presented in this report.

1. Introduction

> *"For gains in human development, and improvements in the lives of the poor, investments in rural water have few rivals."* -United Nations Development Programme (2006)[1]

1.1 The Health and Economic Benefits of Expanding Public Water Supply

Reliable access to safe and affordable drinking water is necessary for human health, development, and dignity.[1–4] Consumption of unsafe drinking water is associated with a substantial burden of disease.[5–8] Chronic exposures to heavy metals, disinfection byproducts, and other contaminants in drinking water are known to cause or contribute to adverse health outcomes such as bladder, colon, kidney, liver, pancreas, rectal, and stomach cancers, as well as coronary heart disease, hypertension, and stroke.[9–12] In 2010, the United Nations (UN) recognized the human right to safe drinking water (as did California in 2012), [2–4,13] however, this right has been unevenly realized in the US where many rural and lower-income rural populations still lack reliable access to safe drinking water.[14–17]

With regard to economic returns on investments in water supply and sanitation, an analysis conducted by the UN's World Health Organization concluded that "combined water supply and sanitation interventions have a benefit-cost ratio of $4.3 at the global level."[18] The non-profit agency WaterAid notes that "upgrading basic services to safely managed water, sanitation, and hygiene infrastructure is a long-term investment that will yield net benefits of $37–86 billion per year [globally], avoiding up to 6 billion cases of diarrhea… between 2021 and 2040." [19] With regard to the US specifically, the American Society of Civil Engineers concluded in a recent report that "Full funding of water infrastructure needs [in the US] would create nearly 800,000 new jobs by 2039… [and that] Increased reliability and water quality would also increase productivity and efficiency in other sectors like manufacturing, leading to job gains." [20]

1.2 Drinking Water Quality and Health in Rural American and Appalachia

UN data indicates that ~1.8 million people living in rural areas of the US lack reliable access to safe drinking water (Cohen's calculation based on data in Annex 3 of a recent UN report[21]); however, relatively little research has focused on drinking water quality disparities in rural areas of the US. For Americans with access to utility-supplied and EPA-regulated drinking water, rates of health-based violations are highest in lower-income rural areas overall, and Appalachia is one of four regional clusters with the highest rates of health-based violations and incomplete plumbing (i.e., no hot and cold running water or a functioning sink, bath, or shower).[17,22] Millions of rural households without utility water rely on groundwater (and bottled water) of variable quality.[23–27]

Compared to the US overall, the Appalachian region is impacted by substantial disparities in health outcomes, including higher mortality rates for 7 of the 10 leading causes of death in the US, and higher rates of cardiopulmonary disease and cancer - such health disparities are even more pronounced in Central Appalachia.[28–33] However, our understanding of which subregions, communities, and populations in Appalachia have higher risks of exposure to contaminated drinking water is severely limited by a lack of previous research and data.[31] Our understanding of associated health outcomes is more limited still. Although ~12 million Americans are estimated to suffer from neglected parasitic infections,[34,35] a 382 page report on "Health Disparities in Appalachia" made no mention of water, sanitation, or enteric diseases.[28]

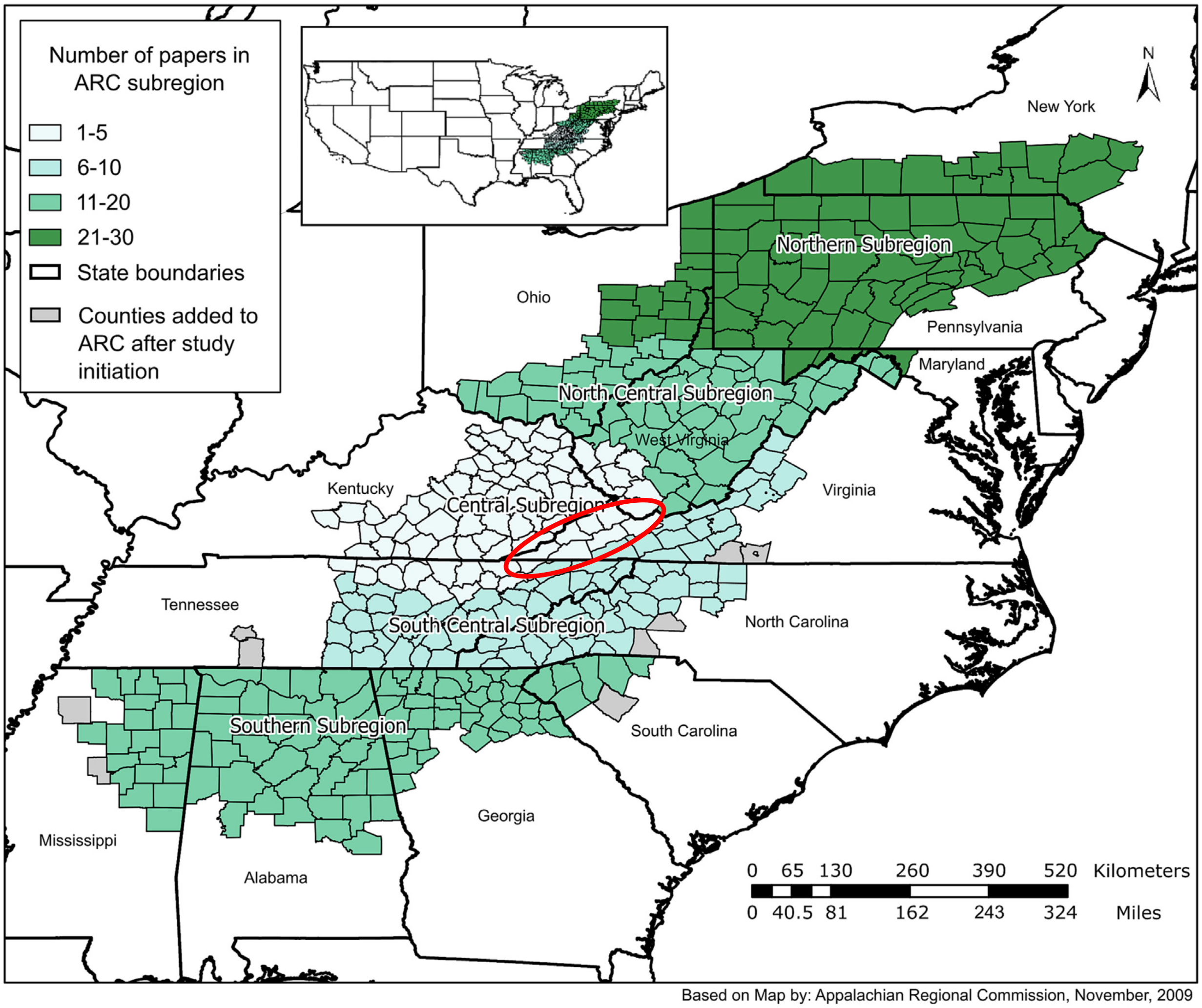


Figure 1: Eligible water-and-health studies identified by region of Appalachia.
Source: Reproduced from Darling et al. (2023)[36]

1.3 Safe Water Access and Health in Southwest Virginia

To better understand the state of research in this domain, we (Cohen Research Group) conducted a systematic review and meta-analysis study focused on water and health research studies conducted from 2000-2020 in Appalachia.[36,37] Of the 3,452 records identified for screening, 85 met our eligibility criteria. Most studies were conducted in Northern (32 %, n = 27) and North Central (24 %, n = 20) Appalachia, and only 6 % (n = 5) were conducted exclusively in Central Appalachia – the region which includes the coalfield counties in far southwest Virginia (see red circle in Figure 1). One of our central conclusions from this review and meta-analysis was that there is not enough available data to draw any clear conclusions about the state of water quality, let alone associated health outcomes, in Central Appalachia.

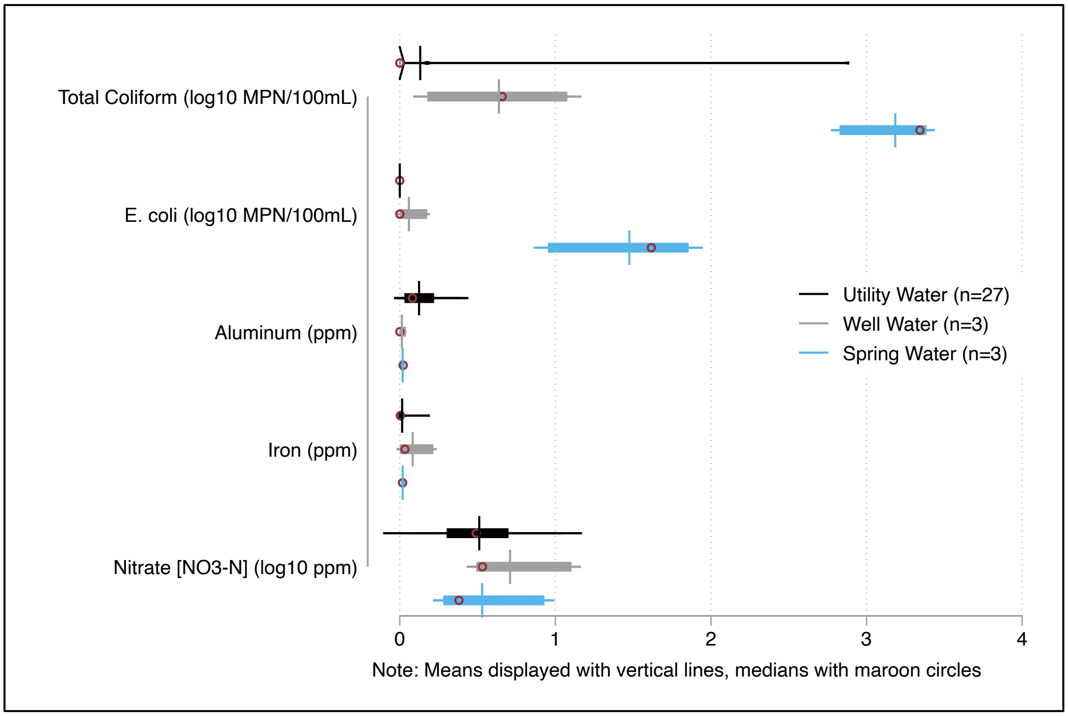


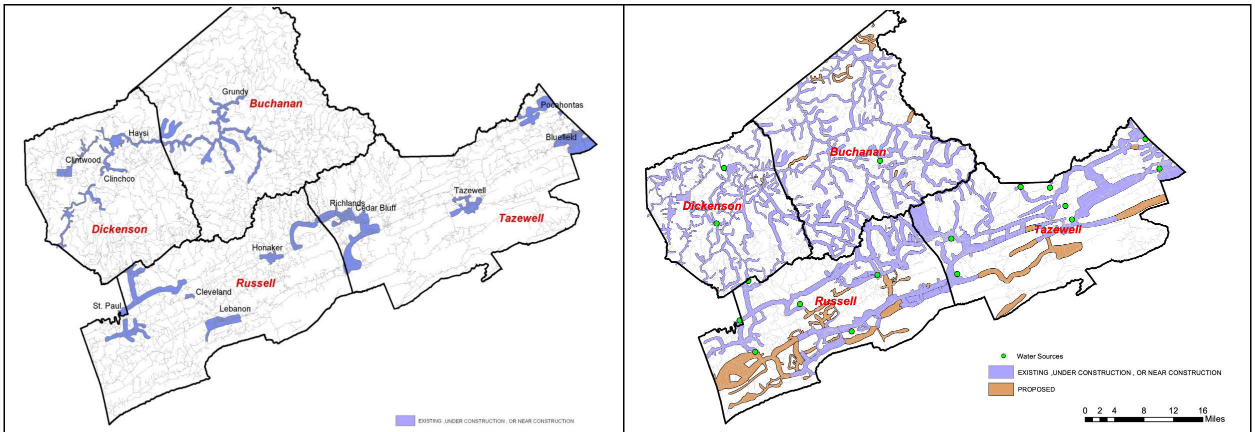
Figure 2: Water quality results from 33 households in Lee and Wise counties.
Source: Reproduced from Cohen et al. (2024)[38]

As shown in the ARC's 2017 Health Disparities in Appalachia report and other sources, health disparities are higher in Central Appalachia compared to other regions.[28–33] In the coalfield counties of Central Appalachia - where this project, and the Cohen Research Group's broader work and research effort is focused - health disparities are particularly acute, and some studies have observed that populations in coal-producing counties exhibit poorer health outcomes compared to non-coal producing counties.[39,40]

In 2021, we (Cohen Research Group et al.) conducted a small study and collected drinking water samples and survey data from a small community of nine rural homes using well water in Wise County. In water samples from 33% (n=3) of these homes we detected *E. coli* (an indicator of fecal contamination), specific enteric pathogens (e.g., *Campylobacter*), and iron and nitrate (NO3-) at concentrations above EPA's standards.[27] In 2022, we initiated a similar study in Wise and Lee counties, collecting data from 33 households (83 individuals) with utility-supplied water and well or spring (Figure 2).[38] Findings from these two studies indicate that risks of exposure to microbiological contaminants in drinking water in far southwest Virginia are relatively high for households using well and spring water.

1.4 The Coalfield Water Development Fund

The Coalfield Water Development Fund (CWDF) is a non-profit established in 1996. CWDF has provided >$10 million in grants to help close funding gaps and increase the affordability and accessibility of public water supply in low income and rural communities in southwest Virginia. Specifically, CWDF has focused its efforts in the coalfield counties in two Planning Districts: Cumberland Plateau (Buchanan, Dickenson, Russell, and Tazewell counties) and LENOWSICO (Lee, Scott, Wise counties, and City of Norton).

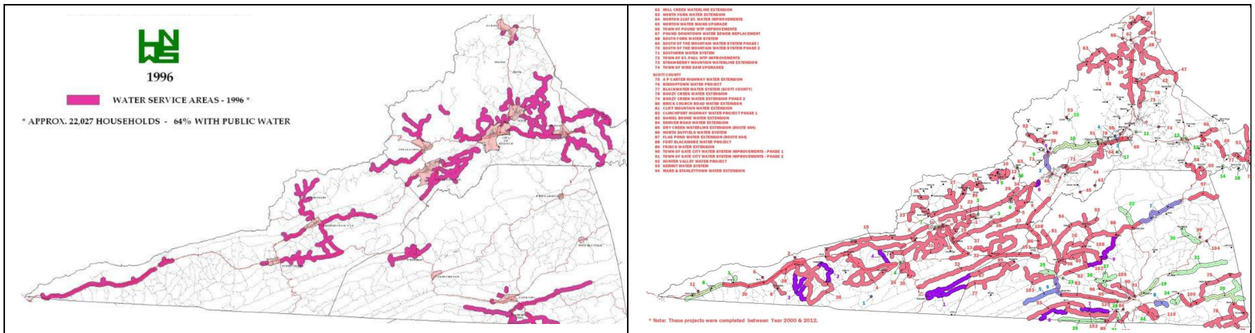


Cumberland Plateau: Public Water Supply, 1990	Cumberland Plateau: Public Water Supply, 2019

Figure 3: Cumberland Plateau Public Water Supply.
Source: Maps created by Cumberland Plateau PD

After the CWDF’s inception, ~$10.3 million was obtained through federal and state legislative action following the documentation of a compelling need for expanded water supply in far southwest Virginia, and the attendant development of a clear plan for addressing this need.

With the reduction of coal production in southwest Virginia over the last few decades, as well as significant population decline, many water and wastewater utilities in Appalachian coalfield counties struggle to maintain sufficient service delivery. Because of the complexities of getting sufficient funding from many federal/state sources for small drinking water projects, it has been a challenge for many communities to extend water service or upgrade existing service without raising rates beyond what can be afforded by many residents in the region. The CWDF has helped address such funding gaps and has focused their efforts on projects that required a high percentage of grant funding but that might not otherwise receive sufficient funding support to proceed.



LENOWISCO: Public Water Supply, 1996	LENOWISCO: Public Water Supply, 2012

Figure 4: LENOWISCO Public Water Supply.
Source: Maps created by the LENOWISCO PD

Thus, in addition to providing financial support for the expansion of utility-provided water supply in the region generally, CWDF’s financial support has enabled many smaller projects that might not otherwise have moved forward. These efforts have contributed the substantial expansion of public water supply from public and EPA-regulated Public Water Systems in the region (see Figure 3 and Figure 4). As described in more detail below, much of proposed analysis will center on the use of detailed project data from CWDF, including: project names, locations, and dates; CWDF-secured funding and other funding amounts per project; and the number of direct beneficiaries (households and individuals).

1.5 Primary Study Objectives

The CWDF reports data on the grants it provides to VDH and EPA on an ongoing basis, but the CWDF has been unable to independently quantify the impacts of its funding due to a lack of research capability and resources. This will be the first independent evaluation CWDF’s cumulative work accelerating and expanding public drinking water development and access in southwest Virginia.

This proposed research project is designed to characterize, quantify, and assess some of the key public health and socioeconomic impacts of CWDF’s funding support efforts over the last ~25 years in the coalfield counties of far southwest Virginia (Buchanan, Dickenson, Lee, Russell, Scott, Tazewell, Wise, and the City of Norton). Our overarching objectives for the project overall are as follows:

1) Characterize and quantify historic and current access to public water supply and ground/well water in seven counties and one city over the study time period as well as associated socioeconomic indicators.
2) Extract, calculate, and compare annual statistics and trends for CWDF-funded projects at planning district and county scales by project size, households served, costs per household and individual, etc.
3) Use Quantitative Microbial Risk Assessment (QMRA) to estimate the burden of infection and morbidity associated with drinking well water in the counties where CWDF has supported water supply projects.

2. Methods

2.1 Data from CWDF on Project Costs, Type, and Populations Served

The CWDF provided detailed summary data on their completed project by year. Information provided included: the name of the project, the funds used and amounts for each as applicable (e.g., Trust Accounts, EPA Accounts, Private Grants [Thompson, Other], Private Admin - Earnings on Priv, Reserve Account, Liquidity Reserve - Earnings), the total amount of funds allocated to each project from grants, and the total from matching funds, the numbers of households and individuals served by each project, and multiple maps (in hard copy) for many of the completed projects.

2.2 County-level Population Served by Water Utilities

In the US, public water systems (PWS) that have ≥15 connections or serve ≥25 residents are subject to EPA's Safe Drinking Water Act (SDWA) regulations.[41] Passed in 1974 and subsequently amended, the SDWA establishes nationally applicable regulatory standards for drinking water quality, treatment, monitoring, and reporting. PWSs are classified as community water systems (CWS) or non-community water systems, with the former serving the same population over a given year. As part of their reporting obligations, PWSs also report the number of connections served and the estimated number of people served (i.e., the served population). While historic data about PWS and SDWA violations are publicly available through EPA's Safe Drinking Water Information System (SDWIS), the population served data for each PWS is overwritten when new data are entered, typically on a quarterly basis.

Central to our analysis was an understanding of the number of people in each county with and without utility provided water per year from ~1996 to 2023. While the data provided by CWDF enabled us to compile total numbers of households and individuals served by CWDF-supported projects per year and per county, without baseline data on the number served for each year we were not in a position to assess CWDF's relative contribution to utility supply expansion overall. Fortunately, we were able to secure much of the historic population served data through two different outreach efforts.

With support from CWDF, we contacted the VDH, Office of Drinking Water, Field Office in Abingdon, a town in Washington County in southwest VA. The acting director, Dr. David Dawson, and his colleagues at the Abingdon office reviewed water system inspection records for the counties in question, and compiled available data on reported population served by CWS. In August 2024 they shared these data with us. For the systems for which data were available/provided, most data covered the period from ~2010 to 2023. For some systems the population served data were available for most years, whereas for others they were available only every three years, or for some, every five years or more. We filled in missing data using a next-neighbors approach based on the assumption of stable linear trends between data points. However, the resulting dataset was still missing observations for a number of systems, and the quality of the underlying data (i.e., the number of years with reported vs. estimated observations) was highly variable, with some counties having near complete data for the time range of 2010-2023, and other counties having only a few observations for only a few systems.

Following parallel efforts to secure this historic population served data directly from EPA, with support from the CWDF and a Program Officer at the Appalachian Regional Commission, in October 2024 an EPA employee in EPA Region 3 (covering VA), in the Communities & Technical Assistance Branch, shared a curated dataset with us containing served population data for ~100 systems from 2013-2023. We used these data for the QMRA analyses and to calculate annual totals of the population served by county for the analyses described below. Summary data on the total estimated number of people served by Public Water Systems by county and year are provided in Table S1.

2.3 County-level Income and Demographic Data

Median income and poverty rate data were obtained the US Census Bureau's Small Area Income and Poverty Estimates program.[42] Estimated annual county population data were obtained from the Virginia Population Estimates data product produced by the UVA Weldon Cooper Center for Public Service.[43] Note: For our analyses, percent change year over year was calculated using a simple time series model where the response was log transformed and the only predictor was year (this kind of model produces a slope estimate that can be interpreted as a percent increase).

2.4 Quantitative Microbial Risk Assessment

For our QMRA analyses, we used location-specific QMRA inputs, CWDF project data, and demographic and socioeconomic data described above, to estimate the health benefits for households and individuals who gained access to utility-supplied water (and who are assumed to have previously had access to well or spring water as their primary water source) at county and sub-county levels by year for the period from 2013 to 2023.

QMRA is a systematic way to interpret quantitative scientific data in the context of calculating the probability of different health outcomes to support water safety management decisions.[44] The QMRA framework uses exposure data combined with dose-response information and data on the distribution of environmental contamination to assess risk. QMRA has been employed in assessing health risks related to drinking water across various scenarios involving waterborne pathogens such as viruses, bacteria, and protozoa.[45,46] The framework consists of four steps:

i) hazard identification;
ii) exposure assessment;
iii) dose-response modeling; and
iv) risk characterization.[47]

Hazard identification/problem formulation: Unlike public water systems, there is relatively limited publicly available data on well and spring water quality in the US. To predict health risk, we will analyze *Campylobacter*, *Cryptosporidium*, *E. coli*, and *Giardia (G. lamblia)* – enteric pathogens which represent four of the most prevalent and harmful water-borne microorganisms.[48] According to the VDH's monthly morbidity surveillance reports for reportable diseases, *G. lamblia, Campylobacter, and Cryptosporidium* are among the top pathogens that cause the majority of the reportable waterborne diseases in Virginia's southwest.[49] Data from recent studies of well water quality in Pennsylvania[50] and Minnesota[51] also support the selection of these pathogens, which have also been linked to notable waterborne disease outbreaks elsewhere in the US.[52,53] In addition, due to their well-characterized dose-response relationships, moderate to long persistence in water sources, high infectivity, and moderate to high resistance to disinfection, these are appropriate proxies for waterborne pathogens generally.[44]

Exposure assessment: The objective of the exposure assessment in this QMRA is to calculate the potential exposure dosages and concentrations of the chosen pathogens for the affected population. Pathogen concentrations in well water will be one of the key variables measured for the exposure assessment. Pathogen concentration values will be gathered from previously published literature.[50,54] The percentage of the exposed population (to be calculated from CWDF reports and data on the number of households and individuals served by CWDF-supported projects by location and year), the frequency of exposure,[55] and the volume of water ingested per day (for children and adults) will be assessed based on published literature[56] and reports from organizations such as the US CDC, VDH, and relevant location-specific field studies (Table 1). Census data will be used for location-specific demographic data estimates and inputs. For exposure, we assumed households with well water would be drinking it consistently for the entire year (i.e., 365 days). However, this assumption is undoubtably an overestimation, as some households may use bottled water some, most, or all days as a primary source of drinking water.

Table 1: QMRA Exposure assessment parameters

Parameter	*Distribution*	Distribution description	References
Water consumption	uniform	Min: 1L Max: 2L	Bivins (2017) [57]
E. coli (non-speciated) concentration in private well water or spring water (MPN/100 ml)	lognormal	Mean = 8.44 Std. dev = 17.36	Cohen Research Group studies [a]

[a] Pooled results from tested water samples (duplicates; collected by trained teams) from 42 rural households on well or spring water in far southwest VA and 12 households on the border in northeast TN collected from 2021-2024.

Dose response: The probability of infection for ingesting *G. lamblia*,[58] and *Cryptosporidium*,[59] are best characterized with an exponential dose−response model, which will be used for assessing the health risks associated with these two pathogens as presented by equation 1, which is described by parameters k and the ingested dose, d. Equation 1) $Prob[Inf] = 1 - (exp)^{(-kd)}$. A beta-Poisson model will provide the most appropriate fit model for *E. coli* [60] and *Campylobacter* [61] and thus will be used to predict the risk associated with these pathogens as described by Equation 2, where N_{50} is the median infectious dose and alpha (α) is the beta distribution parameter.

$$\text{Equation 2)} \qquad Prob[inf] = 1 - [1 + dose\frac{(2^{\frac{1}{\alpha}}-1)}{N_{50}}]^{-\alpha}$$

For each reference pathogen, we will use dose response parameters from optimized published QMRA models (Table 2).[62]

Table 2: QMRA Dose-response parameters

Pathogen	Dose–response parameter	Value	References
E. coli	α	0.155	QMRA Wiki (2023) [62]
	N_{50}	2,110,000 CFU	
Campylobacter	*pending*	*pending*	
Cryptosporidium	*pending*	*pending*	
Giardia	*pending*	*pending*	

Risk Characterization: For our study, the annual probability of infection associated with exposures will be determined by applying Equation 3 where the Prob[annual inf] represents the annual probability of infection, Prob[inf] represents the probability of infection for a single exposure, and N is the number of exposures per year expressed in days.

$$\text{Equation 3)} \qquad Prob[Annual\ Inf] = 1 - (1 - Prob[Inf])^{N}.$$

The risk of annual infection (Prob [Annual Inf]) will then be converted into the risk of diseases (Prob[Annual Ill]). Equation 4 presents the model of the annual risk of diarrheal disease, where (Prob[ill/inf]) is the risk of illness.[63]

$$\text{Equation 4)} \qquad Prob[Annual\ Ill] = Prob[Annual\ Inf] * \ Prob[ill/inf].$$

By bootstrapping the model using statistical analysis software (R Development Core Team, CA, USA), we will also estimate the median, mean, their corresponding confidence intervals, and percentiles of the probability of illness. Rank correlation and tornado analysis will also be used to assess the sensitivity of predicted risks of illness to changes in the input variables. Sensitivity analysis will also be performed to determine risk reductions for the proportion of households estimated to have used home filtration systems and bottled water.

Affected Population using well water: The number of impacted households and people will be calculated using CWDF data. For estimating the total affected population, we will use census data. VDH and DEQ data will be used to extrapolate and validate estimated population proportions using well water.

Burden of Disease Calculations: We will combine the probabilities of illness for each reference pathogen with the total estimated number of well water users from the CWDF data to calculate the total number of illnesses, diarrheal disability-adjusted life years (DALYs) attributed to the consumption of contaminated well water. The DALY is a measure, an estimate, of the cumulative number of years lost due to illness, disability, or death for a given exposure or for multiple exposures, depending on how calculated. We will also attempt to estimate the dollar value of DALYs lost for the affected population. We will compare estimated annual burdens of diarrheal disease for each reference pathogen to the health-based target risk value of 10^6 DALYs/person/year (as per convention) (Table 3).[64] DALY calculated in this report only calculates the years lived with disability (YLD) for the population affected by illness, but it does not account for premature death (YLL). Similarly, analyses do not account for acquired immunity for those with chronic pathogen exposures.

Table 3: QMRA Parameters used for DALYs calculation

Parameter	Value	Note	Reference
Disease duration in years	0.02	Considering acute moderate-to-severe diarrheal illness lasting 7 days	Schilling (2017) [65]
Disability weight	0.188	Considering Moderate cases	Salomon (2015) [66]
Probability [Illness if infection]	0.15	15% probability of illness given infection (estimate based on challenge study infectious dose and exposure comparison with *Campylobacter*)	Croxen (2013) [67] (Schilling (2017) [65])

3. Results

3.1 Regional and County-level Median Incomes and Poverty Rate Trends, 1993-2023

Median incomes in the coalfield counties for the year 2022 ranges from about $40,000 in the poorest county, Buchanan County, to about $50,000 in Russell and Tazewell counties. Overall, median income in the coalfield counties of Virginia is substantially lower than the US overall median income of ~$75,000 (Figure 5).

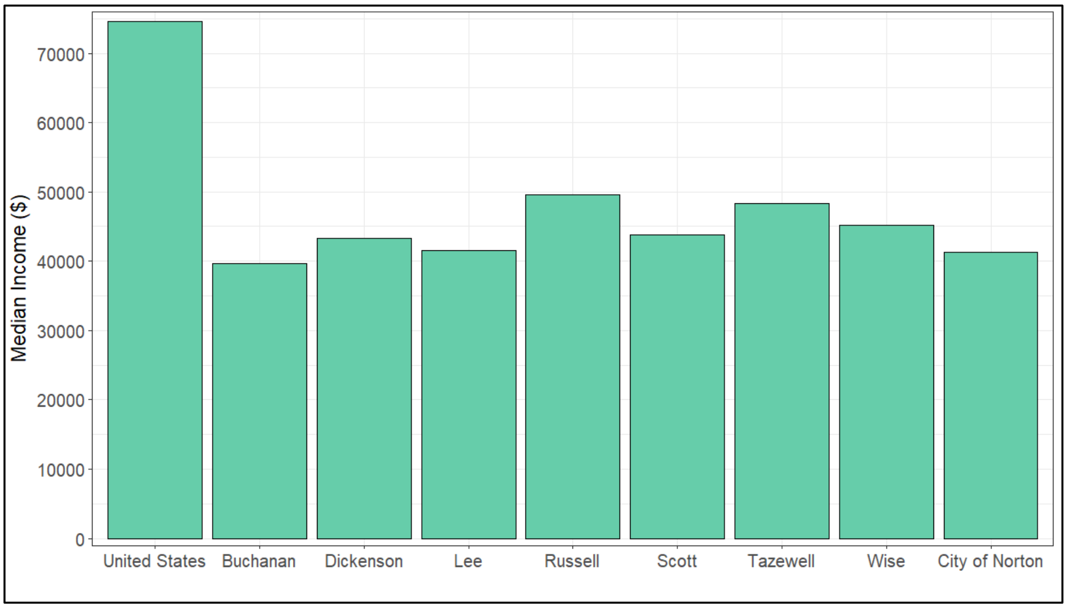


Figure 5: Median Income in Virginia's Coalfield Counties Compared to US Overall (2022)

Since the late 1990s, county-level median incomes in the region have increased at a relatively stable rate of ~2.1% year-over-year. However, inflation-adjusted median incomes have been relatively flat, and increased by only about 0.5% year-over-year for this same time period.

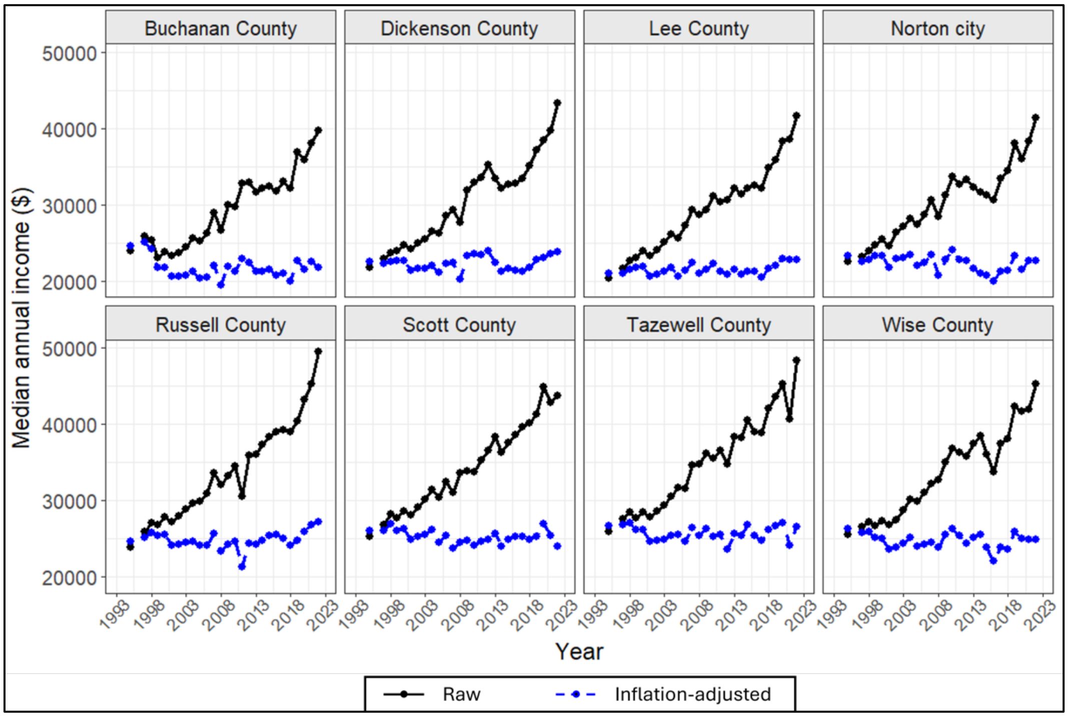


Figure 6: County-level Median Annual Income Trends 1993-2023, with and without Inflation Adjustment

Related, poverty rates in Virginia's coalfield counties have increased overall during this same time period at a range across counties of ~0.2% to 0.8% year-over-year (Figure 7).

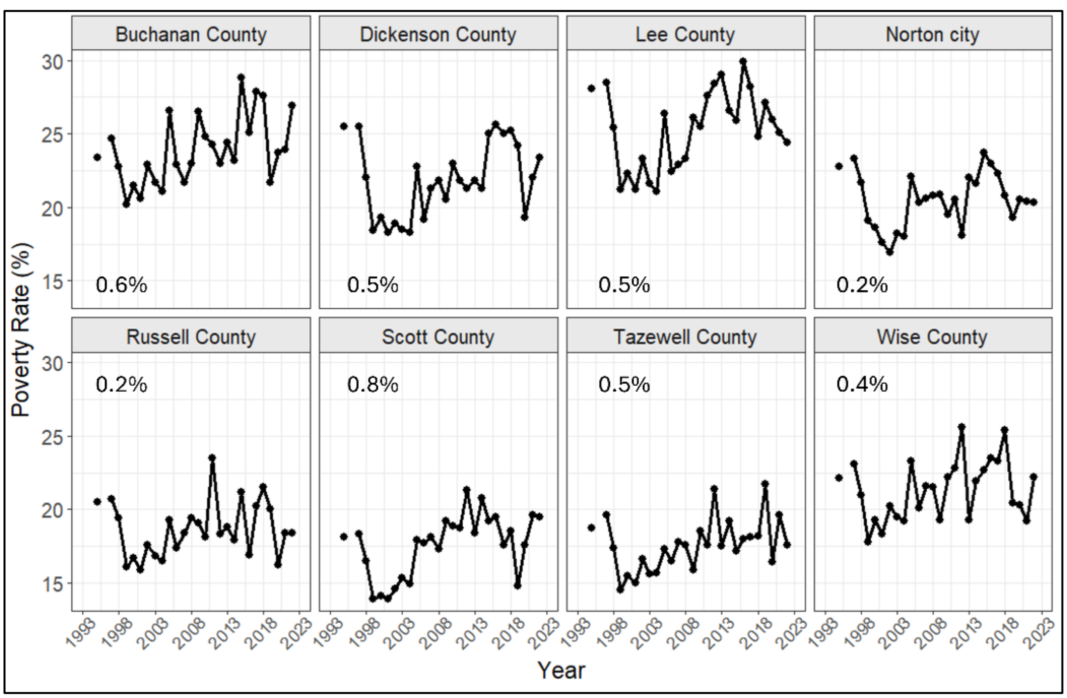


Figure 7: County-level Poverty Rates, 1993-2023

3.2 Overview of CWDF Investments, 1993-2023

Between 1996 and 2023, CWDF invested $9,136,085 supporting projects to expand public water supply for 12,388 people across the coalfield counties of Virginia. Over this same time period, CWDF invested an additional $1,802,922 to support projects focused upgrading and otherwise improving water utility infrastructure in the region (Figure 8). Overall, thanks to the CWDF, a total of 129 water supply infrastructure projects have been completed in Virginia's coalfield counties.

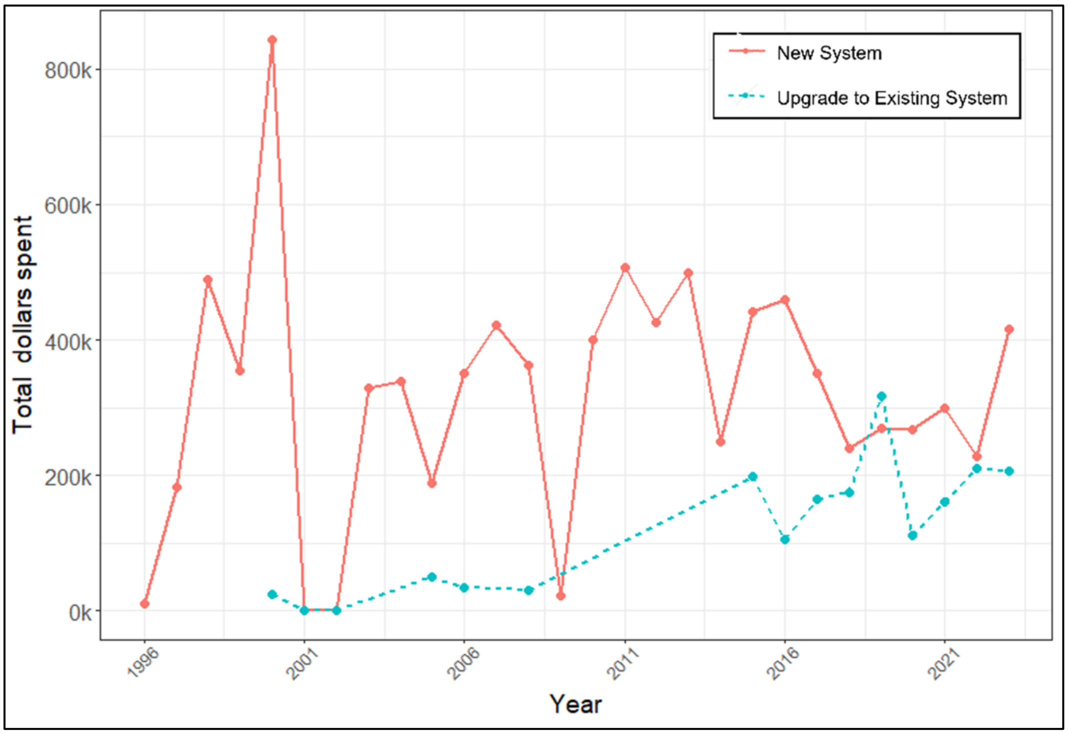


Figure 8: CWDF Total Investments by Year for New System and System Upgrade Projects

Since its inception, CWDF has steadily increased its financial contributions to improving utility-supplied water access in the coalfield counties (Figure 9), increasing spending by ~4.6% year-over-year. However, when annual spending is adjusted for inflation, the year-to-year average falls to ~2.4%.

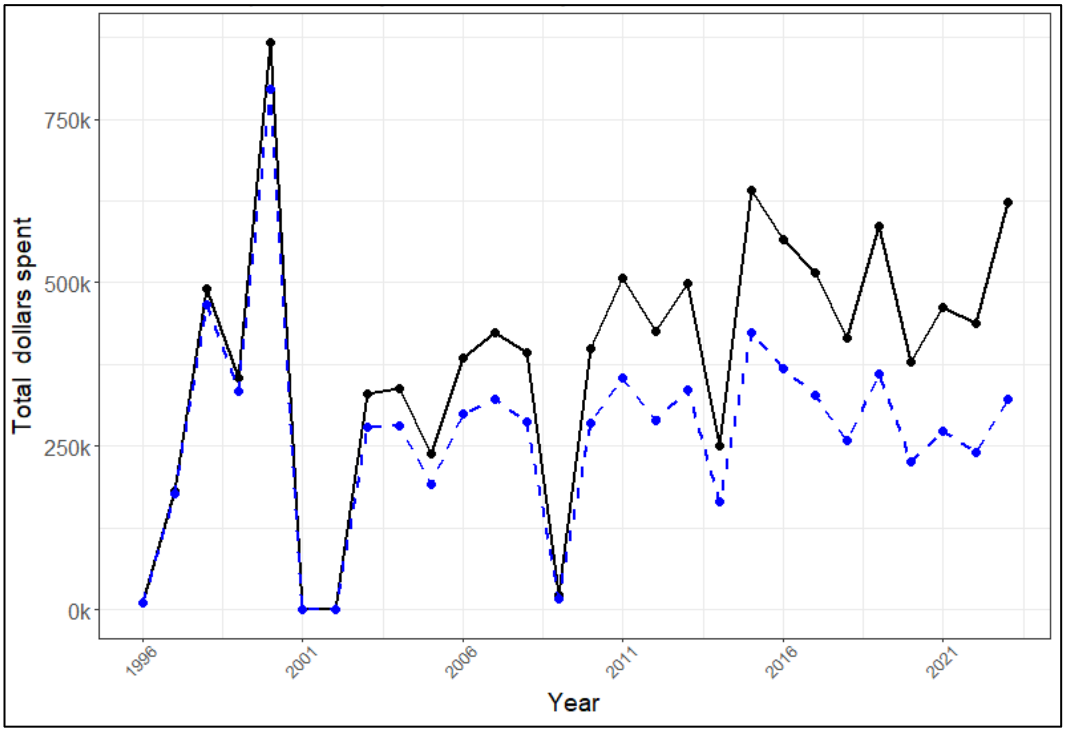


Figure 9: CWDF Total Annual Project Expenditures (1993-2023)
Unadjusted (black line) and inflation-adjusted (blue dashed line) trends

In the most recent ~10-year period of the 30 years of data covered, CWDF has increasingly contributed funds to support water infrastructure upgrades that provide critical maintenance to existing systems. The people impacted by these investment and projects are not included in our data set of total households and persons impacted, but comprise a substantial portion of more recent CDWF investments (Figure 8). Total annual CWDF investments by county are shown in Figure 10.

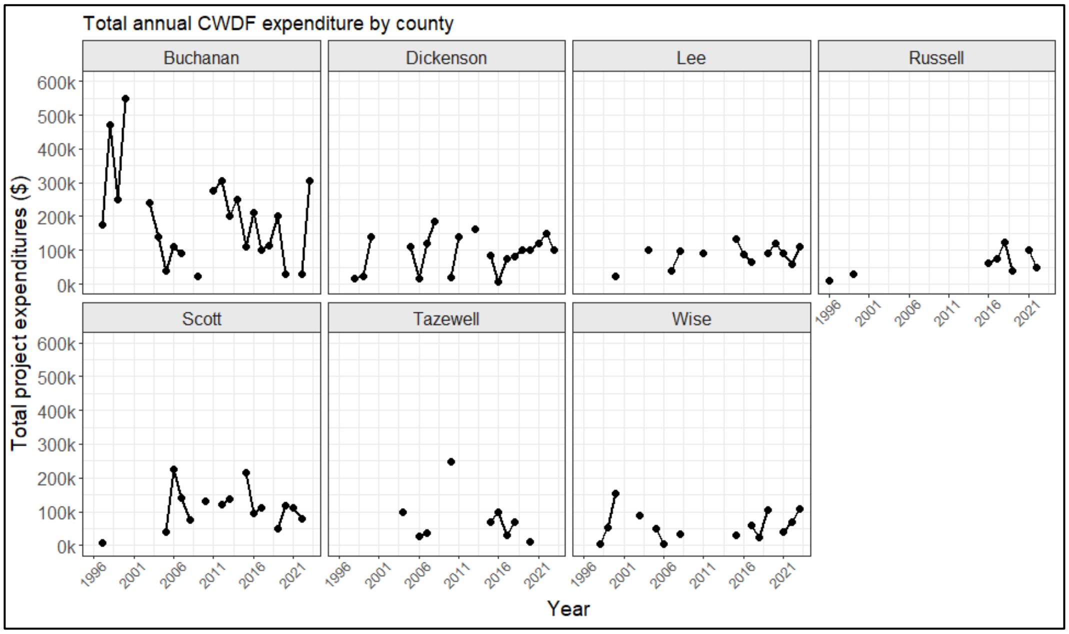


Figure 10: Total Annual CWDF Investments by County, 1993-2023

Another important element of CWDF's support to utilities has to do with the cost-per-connection to extend service to households in a given region. Many sources of federal and state funding for utility supply expansion have limits on the maximum cost-per-connection, and CWDF has been in a position to help utilities bridge needed gaps in funding to cover projects with relatively high average costs-per-connection. Summary data for average per-project cost-per-connection by year and county for CWDF-supported projects are provided in Figure 11.

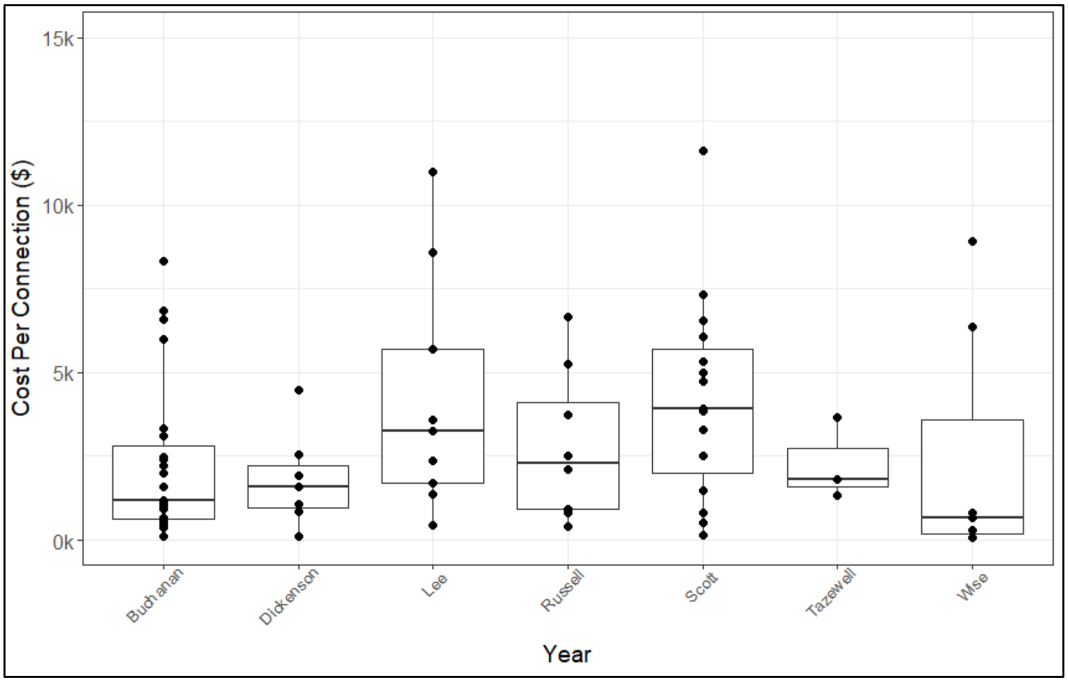


Figure 11: Boxplots of Average Per-project Cost-per-connection by Year and County for CWDF-supported Projects
Note: For improved visualization, figure excludes one data point of ~$24,000 for Lee County

3.3 Number of People Served by CWDF-supported Projects, 1993-2023

The CWDF has had the most per capita impact in terms of new access to public water in Buchanan County, where it has played a role in providing nearly a third (~27%) of the population with public water access, followed by Dickenson County (~10%) (Figure 12).

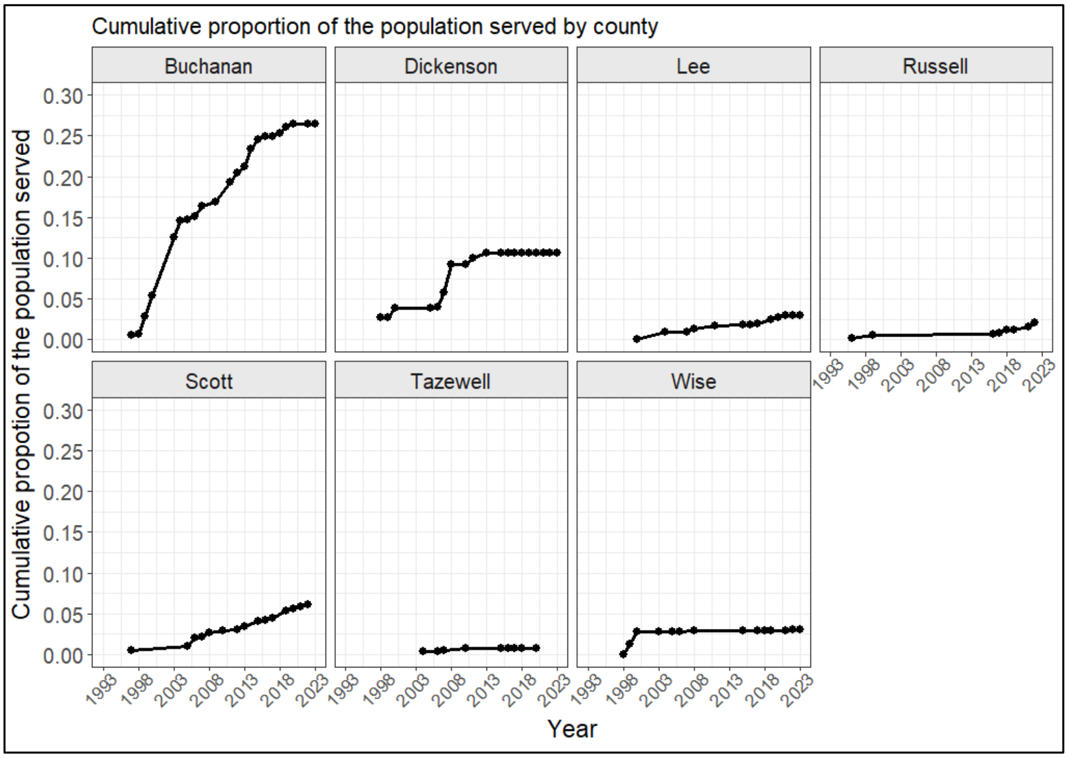


Figure 12: Cumulative Proportion of County Population Served by CWDF-supported Projects, 1993-2013

However, the total number of people served by their efforts has generally decreased by about 4.9% (±2.4%) year over year (Figure 13), suggesting that projects aimed at improving access to public water supplies have been able to target increasingly remote regions as water infrastructure has improved in the region, and more funding has been used to support infrastructure needs of existing systems (Figure 8).

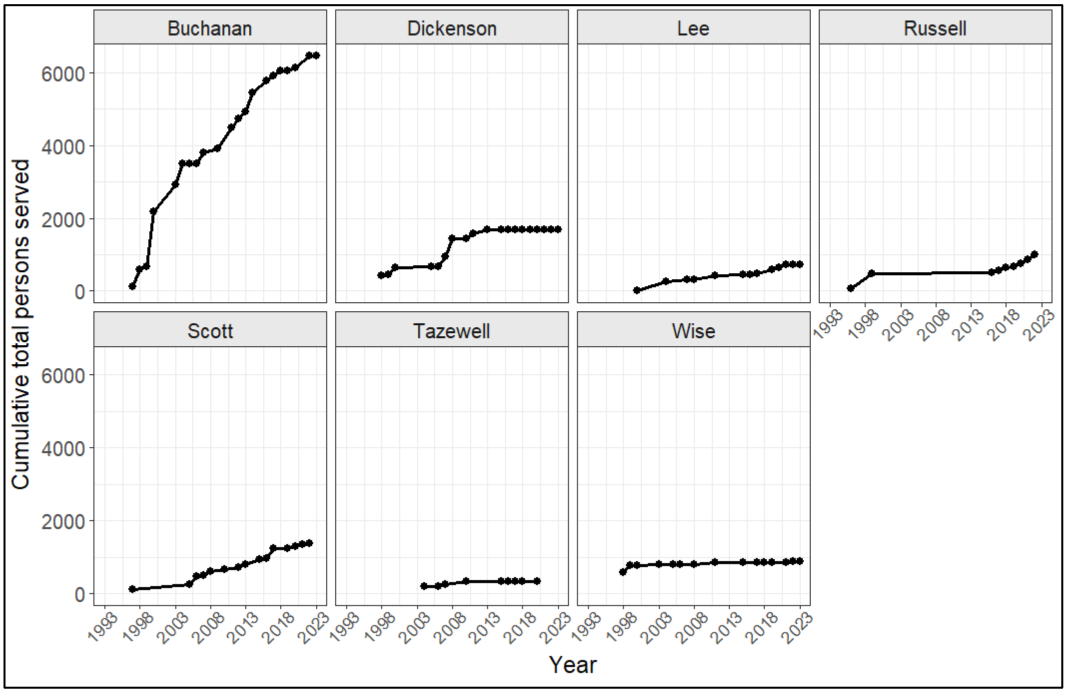


Figure 13: Cumulative Total County Population Served by CWDF-supported Projects, 1993-2013

Overall, CWDF has had a considerable impact on expanding access to utility-supplied water in Virginia's coalfield county. The relative contributions of CWDF-supported projects for 2013-2023 (years for which we have relatively reliable and comprehensive data on the total populations served by county overall) can be seen in Figure 14.

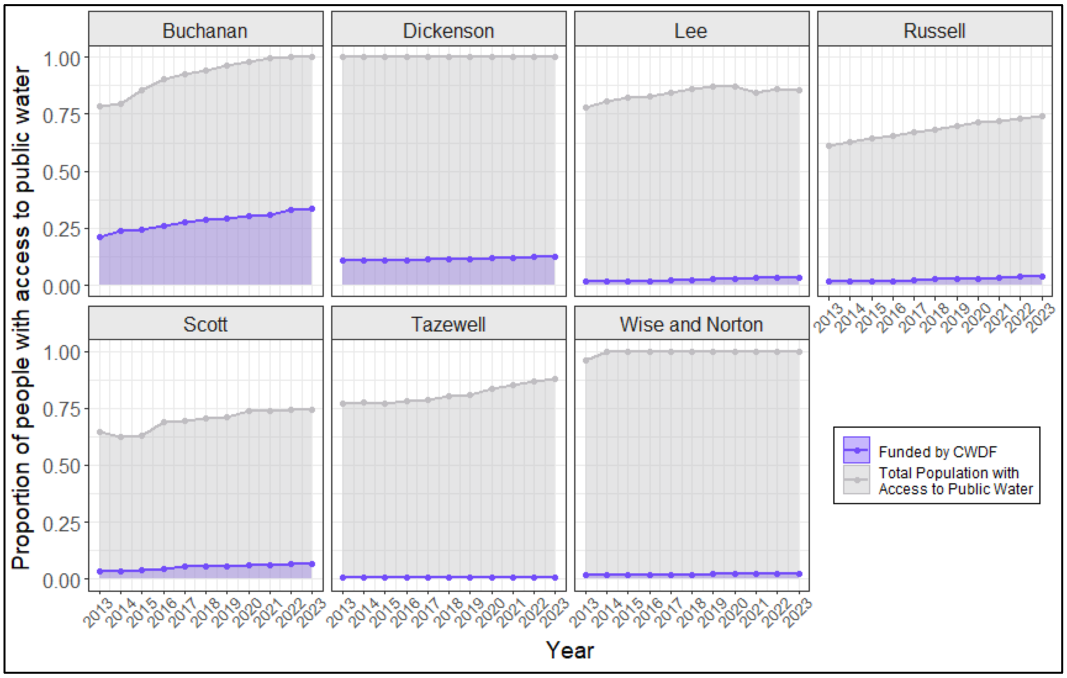


Figure 14: Relative Contributions of CWDF-supported Projects to County-level Utility Water Access

3.4 QMRA Results, 2013-2023

Results from the QMRA analyses described above reveal that populations receiving utility-supplied water via CWDF-supported projects likely benefited from averted infections and illness due to waterborne pathogen exposures that could be expected, on averaged, for populations drinking untreated private well and spring water. The numbers of estimated infections averted range by county based on the populations served and the time at which they were served, ranging from ~708 averted infections in Tazewell to ~12,516 in Buchanan, and a total of 24,923 overall.

Table 4: QMRA Results: *E. coli* Illnesses and DALYS Averted for CWDF-supported Projects

County	***Estimated Mean Total Infections Averted [95% CI]***	***Estimated Mean Total DALYs Averted [95% CI]***
Buchanan	12,516 [5,780 - 21,271]	7.06 [3.26 - 12.00]
Dickenson	3,561 [1,648 - 6,046]	2.01 [0.93 - 3.41]
Lee	1,181 [542 - 2,036]	0.67 [0.31 - 1.15]
Russell	1,427 [653 - 2,483]	0.80 [0.37 - 1.40]
Scott	2,419 [1,118 - 4,154]	1.36 [0.63 - 2.34]

Tazewell	708 [328 - 1,203]	0.40 [0.18 - 0.68]
Wise and Norton	1,812 [840 - 3,076]	1.02 [0.47 - 1.73]
Totals	24,923	13.32

Notes: DALYs averted by switching to utility water were calculated assuming no infections from the utility water supply. CI = Confidence Interval, DALY calculated in this report only calculates the years lived with disability (YLD) for the population affected by illness, but it does not account for premature death (YLL).

Means and confidence intervals for estimated *E. coli* infections averted by county due to CWDF-supported projects are shown in Figure 15. While our QMRA analysis shows that a considerable number of would-be infections and illnesses were averted, it is hard to contextualize these figures, because there is relatively little similar research/analysis on microbiological well water quality in the US, and we lack sufficient data to understand the burden of disease associated with private well and spring water exposures to waterborne pathogens.[68–70]

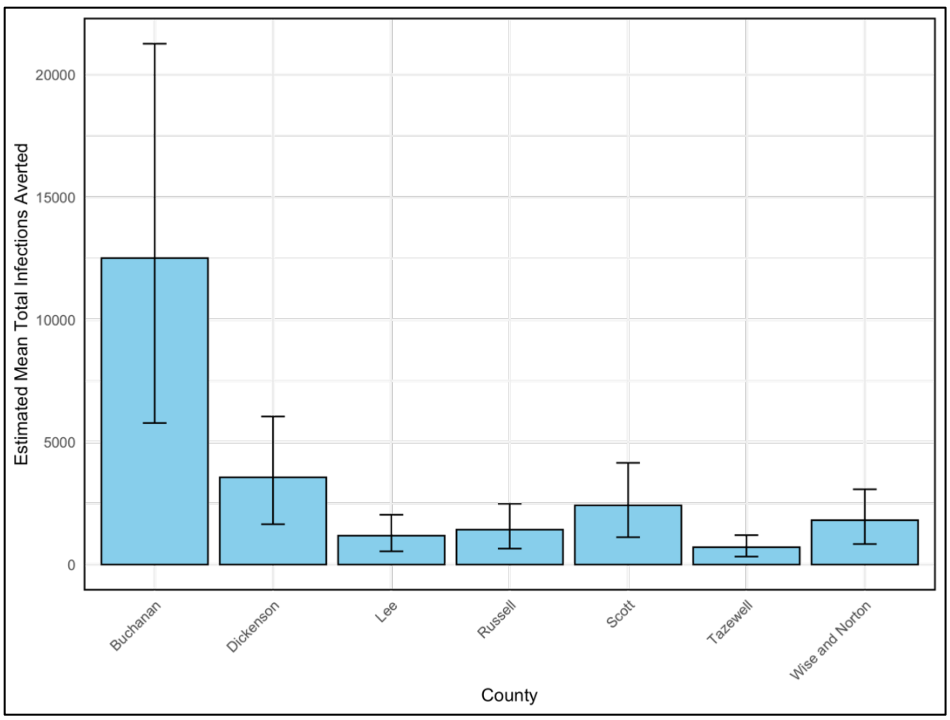


Figure 15: Estimated Total *E. coli* Infections Averted by County due to CWDF-supported Projects
Note: Means and 95% Confidence Intervals (2013-2023)

4. Discussion & Conclusions

4.1 Discussion

A number of key factors associated with how CWDF allocated funding over the ~30-year time period covered are not adequately captured in the data presented above. One such issue relates to the cost-per-connection for new would-be extension projects. While utilities in lower-income rural areas such as much of Central Appalachia have access to a number of Federal and State funding support mechanisms for new projects, one of the key metrics used to help make resource allocation decisions is the cost-per-connection to provide/extend new service. For many of the projects CWDF has supported over the years, part of the service they provided was helping utilities to cover the last remaining portions of the average cost-per-connection not otherwise covered by other funding mechanisms (see Figure 11).

Another key factor relevant to all the analyses above is that of population decline. In all of the counties served by the CWDF, the population has, overall, declined over the last 20+ years (see Table S2). Indeed, across Buchanan, Dickenson, Lee, Russell, Scott, Tazewell, and Wise Counties, from 2000 to 2010 populations declined by an average of -10.7%, and from 2010 to 2020 they declined by an average of -15.6% (approximately -13% overall from 2000-2020), compared to population gains/increases for the State of Virginia of +7.9% and +13% over the same two time periods (data in Table S2). Population loss creates a number of challenges for local governments and utilities. For one, many water treatment (and wastewater treatment) plants may end up having more capacity than is needed (in terms of gallons per day that can be treated), and depending on where population decline occurs, sections of the distribution infrastructure may be less used, which can create water quality and other challenges due to increased "water age".

In addition, for utilities borrowing money to fund water supply expansion projects, population decline can be challenging since it is difficult to accurately forecast future rate recovery, and with it a utility's ability to repay loans with long repayment periods. Within this context, one of the services CWDF has provided is that of helping utilities increase the proportion of grants funds used vs. loan funds for expansion and infrastructure projects, and, more broadly, the ~30 years of benefits that have accrued thanks to CWDF support also demonstrate what can be achieved using an "endowment model" for both initial project support and, importantly, support for future maintenance and upgrade needs.[71]

4.2 Challenges and Limitations

Originally, we had planned to analyze data over approximately 30 years, however, as described above, we were only able to obtain sufficient data on the population served by utilities for the period from 2013 to 2023. In addition, we had initially sought to undertake a fourth objective to "Characterize and quantify historic and current access to centralized and decentralized sewerage and sanitation in all seven counties, as well as associated implications for environmental and public health." However, due to a lack of sufficient data we were unable to conduct analyses for this objective.

As noted above, summary data on the total estimated number of people served by Public Water Systems by county and year are provided in Table S1. However, as demarcated in red font in Table S1, these county-level totals often exceed that of the total estimated population for a given county. There are a number of reasons for this – not least because the population served data are typically estimates by the utilities – including that many people in a given county may be inadvertently double-counted as they may be served by one more community water systems and non-community water systems (e.g., in schools or at rest areas or campgrounds). Thus, for those counties with proportions served >1 it should be assumed that the vast majority of the county population does have access to utility-supplied water, but that household-level access is not actually 100%.

4.3 Conclusions

Our analyses help quantify the substantial beneficial impacts CWDF-supported utility water supply expansion and maintenance projects have provided for Virginia's coalfield counties over the last ~30 years. More broadly, however, there are numerous other benefits for health and wellbeing that come with access to utility-supplied water that are not captured in our analyses but should be considered nonetheless.

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Contributions

Md Rasheduzzaman: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, and Visualization, and Writing – review & editing (focus: QMRA). Alicia Arneson: Data curation, Formal analysis, Investigation, Methodology, Supervision, Visualization, and Writing – review & editing (focus: CWDF project data, US Census and other data). Alasdair Cohen: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Writing – original draft, and Writing – review & editing.

Notes & Disclaimers

As of November 15, 2024, some additional data QA/QC remains to be done, primary analyses and results reported have not yet been independently replicated, and additional QMRA results for other pathogens (in addition to *E. coli*) are pending. We anticipate submitting a manuscript for publication based on this work/report by or before early 2025.

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Supplementary Information

Table S1: Estimates of persons served with utility water by county and year overall and by CWDF-supported projects

County	Year	Cumulative Persons Served by CWDF	Total Persons with Access to Public Water	Estimated County Population	Estimated Proportion of Population with Access to Public Water	Proportion of Population Served by CWDF	Proportion of Total Served that were Served by CWDF
Buchanan	2013	4,931	18,330	23,314	0.786	0.212	0.269
Buchanan	2014	5,437	18,313	22,976	0.797	0.237	0.297
Buchanan	2015	5,437	19,313	22,558	0.856	0.241	0.282
Buchanan	2016	5,770	19,829	22,000	0.901	0.262	0.291
Buchanan	2017	5,921	19,829	21,449	0.924	0.276	0.299
Buchanan	2018	6,036	19,829	21,064	0.941	0.287	0.304
Buchanan	2019	6,036	19,950	20,695	0.964	0.292	0.303
Buchanan	2020	6,141	19,950	20,355	0.980	0.302	0.308
Buchanan	2021	6,141	19,950	19,982	0.998	0.307	0.308
Buchanan	2022	6,453	19,949	19,434	1.026	0.332	0.323
Buchanan	2023	6,453	19,949	19,191	1.039	0.336	0.323
Dickenson	2013	1,674	15,907	15,679	1.015	0.107	0.105
Dickenson	2014	1,674	15,662	15,574	1.006	0.107	0.107
Dickenson	2015	1,674	15,662	15,458	1.013	0.108	0.107
Dickenson	2016	1,674	15,739	15,184	1.037	0.110	0.106
Dickenson	2017	1,674	15,739	14,917	1.055	0.112	0.106
Dickenson	2018	1,674	15,739	14,650	1.074	0.114	0.106
Dickenson	2019	1,674	16,221	14,394	1.127	0.116	0.103
Dickenson	2020	1,674	16,221	14,124	1.148	0.119	0.103
Dickenson	2021	1,674	16,221	13,902	1.167	0.120	0.103
Dickenson	2022	1,674	16,132	13,711	1.177	0.122	0.104

Dickenson	2023	1,674	16,132	13,603	1.186	0.123	0.104
Lee	2013	413	20,354	26,069	0.781	0.016	0.020
Lee	2014	413	20,333	25,190	0.807	0.016	0.020
Lee	2015	443	20,333	24,646	0.825	0.018	0.022
Lee	2016	461	20,220	24,370	0.830	0.019	0.023
Lee	2017	487	20,298	24,103	0.842	0.020	0.024
Lee	2018	487	20,298	23,635	0.859	0.021	0.024
Lee	2019	601	20,175	23,185	0.870	0.026	0.030
Lee	2020	653	19,270	22,173	0.869	0.029	0.034
Lee	2021	716	18,733	22,116	0.847	0.032	0.038
Lee	2022	716	18,733	21,699	0.863	0.033	0.038
Lee	2023	729	18,733	21,955	0.853	0.033	0.039
Russell	2013	473	17,387	28,477	0.611	0.017	0.027
Russell	2014	473	17,657	28,206	0.626	0.017	0.027
Russell	2015	473	18,060	27,966	0.646	0.017	0.026
Russell	2016	503	18,020	27,511	0.655	0.018	0.028
Russell	2017	551	18,158	27,067	0.671	0.020	0.030
Russell	2018	656	18,283	26,704	0.685	0.025	0.036
Russell	2019	669	18,340	26,361	0.696	0.025	0.036
Russell	2020	743	18,423	25,781	0.715	0.029	0.040
Russell	2021	856	18,423	25,639	0.719	0.033	0.046
Russell	2022	1,001	18,551	25,338	0.732	0.040	0.054
Russell	2023	1,001	18,551	25,033	0.741	0.040	0.054
Scott	2013	792	15,108	23,356	0.647	0.034	0.052
Scott	2014	792	14,559	23,263	0.626	0.034	0.054
Scott	2015	926	14,559	23,037	0.632	0.040	0.064
Scott	2016	969	15,736	22,822	0.690	0.042	0.062
Scott	2017	1,223	15,736	22,615	0.696	0.054	0.078
Scott	2018	1,223	15,736	22,362	0.704	0.055	0.078
Scott	2019	1,223	15,736	22,126	0.711	0.055	0.078

Scott	2020	1,284	15,880	21,576	0.736	0.060	0.081
Scott	2021	1,335	15,880	21,534	0.737	0.062	0.084
Scott	2022	1,383	15,880	21,309	0.745	0.065	0.087
Scott	2023	1,383	15,880	21,304	0.745	0.065	0.087
Tazewell	2013	333	34,355	44,479	0.772	0.007	0.010
Tazewell	2014	333	34,367	44,294	0.776	0.008	0.010
Tazewell	2015	333	33,768	43,845	0.770	0.008	0.010
Tazewell	2016	333	33,805	43,363	0.780	0.008	0.010
Tazewell	2017	333	33,805	42,898	0.788	0.008	0.010
Tazewell	2018	333	33,805	42,224	0.801	0.008	0.010
Tazewell	2019	333	33,576	41,582	0.807	0.008	0.010
Tazewell	2020	333	33,749	40,429	0.835	0.008	0.010
Tazewell	2021	333	33,749	39,763	0.849	0.008	0.010
Tazewell	2022	333	34,276	39,470	0.868	0.008	0.010
Tazewell	2023	333	34,276	39,082	0.877	0.009	0.010
Wise and Norton	2013	847	41,911	43,661	0.960	0.019	0.020
Wise and Norton	2014	847	43,066	43,252	0.996	0.020	0.020
Wise and Norton	2015	847	43,066	43,117	0.999	0.020	0.020
Wise and Norton	2016	847	42,728	42,597	1.003	0.020	0.020
Wise and Norton	2017	847	42,728	42,094	1.015	0.020	0.020
Wise and Norton	2018	847	42,728	41,364	1.033	0.020	0.020
Wise and Norton	2019	847	42,728	40,665	1.051	0.021	0.020
Wise and Norton	2020	847	42,728	39,817	1.073	0.021	0.020
Wise and Norton	2021	847	42,728	39,515	1.081	0.021	0.020
Wise and Norton	2022	873	43,034	39,153	1.099	0.022	0.020
Wise and Norton	2023	873	43,034	38,667	1.113	0.023	0.020

Note: 2023 and 2020 county population estimates differ slightly from those reported in Table S2 due to slight differences in when data were retrieved from the US Census Bureau

Table S2: County, State-wide, and Nationwide, Population Growth and Decline from 2000 to 2023

	Population Estimate July 1, 2023	% Change from 2020 - 2023	Population April 1, 2020	% Change from 2010 - 2020	Population April 1, 2010	% Change from 2000-2010	Population April 1, 2000
Buchanan County, VA	19,087	-6.2	20,343	-15.6	24,098	-10.7	26,978
Dickenson County, VA	13,640	-3.5	14,128	-11.2	15,903	-3.0	16,395
Lee County, VA	21,745	-1.9	22,172	-13.3	25,587	8.5	23,589
Russell County, VA	25,477	-1.2	25,784	-10.8	28,897	-4.7	30,308
Scott County, VA	21,433	-0.6	21,569	-6.9	23,177	-1.0	23,403
Tazewell County, VA	39,120	-3.3	40,437	-10.3	45,078	1.1	44,598
Wise County, VA	35,174	-2.6	36,118	-12.9	41,452	3.3	40,123
State of Virginia	**8,715,698**	**1.0**	**8,631,373**	**7.9**	**8,001,024**	**13.0**	**7,078,515**
USA	**334,914,895**	**1.0**	**331,464,948**	**7.4**	**308,745,538**	**9.7**	**281,421,906**

Source: US Census Bureau, https://www.census.gov/quickfacts/fact/table/US/PST045222 (retrieved 2024-11-14)
Note: 2023 and 2020 county population estimates differ slightly from those reported in Table S1 due to slight differences in when data were retrieved from the US Census Bureau