Shenandoah County: Flood and Drought Adaptation Strategies

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Introduction

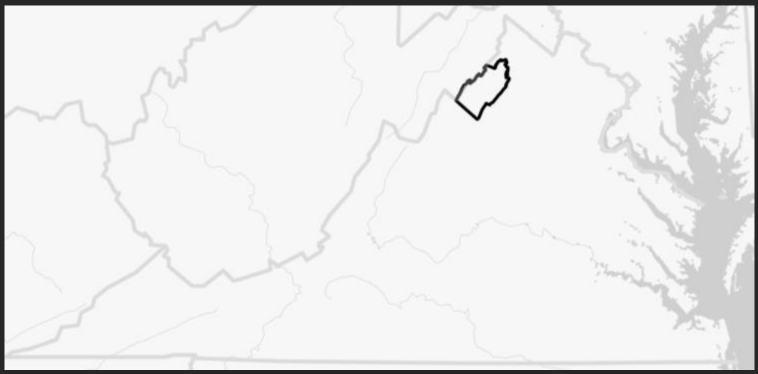
This report is a partnership between the Shenandoah County Government and students from the University of Virginia.

Shenandoah County is a largely rural county in North Western Virginia. Some of the top industries include healthcare, education, and manufacturing. While agriculture is not one of the top industries, farming is a major use of land in the county, using approximately one third of the land[1]. This high agricultural use, as well as the county's topography, increase the area's risk of flash floods, droughts, and algal blooms from runoff. Between 1950 and 2010, there were 55 instances of drought and 2,070 instances of flash flooding in Shenandoah County. Climate change will likely exacerbate many of these issues in the future, making it important to invest in solutions now.

Flash flooding, drought, and algal blooms have the potential to negatively impact the lives and livelihoods of people of Shenandoah County. Around 80 percent of the 44,000 people living in the county use wells as their main source of water, which can leave them susceptible to drought. The county has a median income of $57,000 and a poverty rate of 11 percent. Individuals with lower incomes may experience more difficulty recovering from a flash flood or drought. Water quality issues in Shenandoah County also have the potential to impact areas outside of the county, as the Shenandoah River drains into the Chesapeake Bay.

The goal of this report is to provide insights that might help Shenandoah County begin to address flooding, drought, and algal blooms. Some of the solutions identified could simultaneously alleviate the impacts of drought and flash flooding. Given the risk assessment and stakeholder analysis discussed below, agricultural areas were identified as having a higher risk associated with flooding and drought. However, by implementing some of the best practices identified below, farms could become an important part of the solution to these issues.

[1] National Agriculture Statistics Service



Shenandoah County on Map of Virginia

What is flash flooding?

Flash flooding is one of the most dangerous natural hazards in both rural and urban areas and developing plans for flash flood preparedness is a crucial step towards broader goals of hazard risk mitigation and climate adaptation. According to the National Weather Service, eighty-eight people die on average each year in the United States because of flash flooding. Flash flooding is defined by the National Weather Service as “flooding that begins within 6 hours, and often within 3 hours, of the heavy rainfall (or other cause).” [2] Most flash floods are caused by slow moving thunderstorms, thunderstorms that move repeatedly over the same area, or heavy rains from tropical storms and hurricanes. Additional causes can include dam or levee breaks, or mudslides. Flash floods most frequently occur on small headwater basins. The major difference between flash floods and other types of riverine flooding is that the effects of flash floods generally occur with little, if any, warning over a very short time period and are generally limited to relatively small areas. However, the effects of flash floods are often catastrophic and may, depending on development and land use in the affected basins, result in large loss of life.[3] The intensity of the rainfall, the location and distribution of the rainfall, the land use and topography, vegetation types and growth/density, soil type, and soil water-content all determine just where and how quickly a flash flooding event may occur. Urban areas are generally more prone to flooding in short timespans; the same amount of rainfall over an urban area will cause flooding faster and more severe than in the suburbs or countryside because the impervious surfaces in the urban area do not allow water to infiltrate the ground.[4]

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[2] National Weather Service, 2019

[3] Petersen, 2001

[4] National Weather Service, 2019

Flash floods can roll boulders, tear out trees, destroy buildings and bridges, and scour out new channels. Rapidly rising water can reach heights of 30 feet or more, and flash flood-producing rains can also trigger catastrophic mudslides. Nearly half of all flash flood fatalities are vehicle-related, and the majority of victims are males, however, flash flood risk impacts everyone. In addition to the loss of human life, flash floods can devastate infrastructure and lead to economic losses. In the U.S. in 2019, flash flooding was responsible for over $3.7 billion of economic damage.[5] More specifically, large debris and flood waters can cause structural damage to bridges and roadways, making travel impossible, take out power, telephone, and cable lines, and disrupt or contaminate groundwater, making tap water unfit for consumption. All these impacts threaten human health and safety and incurs huge costs for municipalities.[6] Furthermore, flood waters carry along with them sand, silt, and other debris as they travel. When the velocity of the flash flood slows, it begins depositing this debris, leaving behind large amounts of silt and other debris that can make travel difficult, can harm the natural ecosystem, smother crops, and be costly to remove. Particularly relevant to Shenandoah County, flooding in key agricultural production areas can lead to widespread damage to crops. Crop losses through rain damage, waterlogged soils, and delays in harvesting are further intensified by transport problems due to flooded roads and damaged infrastructure.[7] Because of the infrequent and unpredictable nature of flash floods, many home, business, and other property owners do not consider flash floods when deciding whether to purchase flood insurance, leaving many people to bear the destructive costs of flash floods on their own[8].

One factor that can impact the severity of flash floods are drought conditions; when soil is very dry because of ongoing drought conditions it becomes compacted and impermeable, leading water to pool and runoff the surface. Drought is difficult to define and pinpoint because it is often slow-developing and prolonged.[9] Generally speaking, however, drought is caused by receiving below-average or insufficient precipitation over a period of time. Unlike other natural hazards, there are no watches or warnings to predict when a drought is coming. Thus, being prepared in advance is a key aspect for coping with drought and developing long lasting

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[5] Fernandez, 2021

[6] Teton County, 2021

[7] Queensland Government, 2021

[8] Teton County, 2021

[9] National Oceanic and Atmospheric Administration

strategies for storing water and reducing water consumption are key aspects of drought adaptation.[10]

History of Flash Flooding & Drought in Shenandoah County, VA

Overview

Shenandoah County is a region subjected to a relatively high frequency of both flash flooding and drought. Between 1950 and 2010, there were 55 instances of drought and 2,070 instances of flash flooding.[11] Throughout its history, both drought and flash flooding have strained Shenandoah County's resources and presented consistent threats to life, livelihoods, and property for those living there.

Drought

Periods of prolonged dryness have had an exacerbated effect on Shenandoah County because of its agricultural economy and because roughly "80% of Shenandoah County residents receive drinking water or household water from wells or springs".[12] In the past, Shenandoah county has experienced periods of intense drought. In 2021, officials in Shenandoah County sought drought disaster designation in an effort to facilitate financial assistance from the United States Department of Agriculture (USDA)[13] similar to what the county did in 2018.[14] The 60-month span between December 1962 and November 1967 was the driest on record with less than 2.6 inches of monthly rainfall.[15] The historic monthly average is 3.5".

Editorial reports stretching back into the early 20th century to recent years illustrate the hardships brought about by drought. Patrick Michaels, past president of the American Association of Climatologists, described the magnitude of the 1930 drought by saying "most

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[10] National Drought Mitigation Center

[11] Shenandoah County, VA Natural Disasters and Weather Extremes - USA.com™, 2021

[12] Shenandoah County Comprehensive Plan 2025, 2014

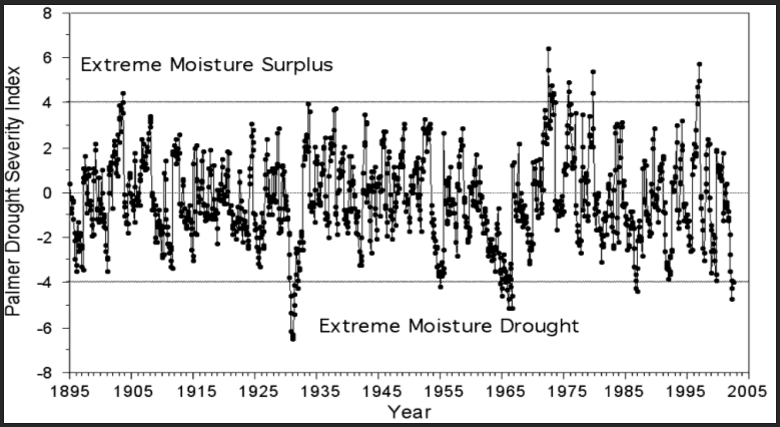
[13] Welch, 2021

[14] Bradshaw, 2018

[15] NOAA, 2021

Mid-Atlantic weather stations average only about one 100-degree day per year. Not in 1930. Rural Woodstock, hard in the middle of the Shenandoah Valley, had 21 of them".[16]

While the drought of 1930 is perhaps the most devastating of historical droughts in Shenandoah County, the region has endured numerous other drought events. In 1977, in the nearby town of Stanley, Virginia struggled "to keep its 1,200 residents and about the same number in the surrounding area supplied with water"[17] and a United States Department of Interior paper from 1979 noted that "crop damage was high and municipal water supplies dangerously low" in the regions surrounding and including Shenandoah County.[18] From 1997 to 2002, Shenandoah County experienced a prolonged drought with many wells in the area reaching record minimum stream flows.[19] The Palmer Drought Severity Index below depicts the severity and frequency of drought up to 2005.



Flash Flooding

Generally, flash flooding in Shenandoah County occurs as a result of precipitation brought about by tropical storms combined with the mountainous topography of the Shenandoah Valley, which allows those storms to stall out over the area. The worst flood of this type to date

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16 Michaels, 2002

17 Grubisich, 1977

18 Matthai, 1979

19 USGS--Drought Watch--Virginia, 2002

was in 1942 when the Shenandoah River crested at approximately 35 feet with anything exceeding 15 considered to be dangerous.[20]

1942 flood: Photo Credit: Loudon County Library

However, flooding in Shenandoah County is almost always discussed in reference to the 1985 “Election Day” flood on November 4th and 5th following Hurricane Juan which a paper would later describe as causing “more damage than the Civil War in the area” and did an (inflation adjusted) nearly $5 million worth of damages in Shenandoah County.[21] Affecting three states, the Election Day flood claimed 34 lives.[22]

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[20] US Department of Commerce, 2021

[21] Prior, 1995

[22] Marcus, 1985

1985 “Election Day” Flood Photo credit: Aubrey Urbanowicz, WHSV; Twitter

Another major flood event occurred in September of 1996, when Hurricane Fran followed an earlier snowmelt related flood event in January. The Shenandoah River crested at 28 feet and flooding affected much of the county. Throughout Virginia, “damage from Hurricane Fran was estimated at 286 million (1996 dollars) and caused eight deaths. Two hundred and thirty-three homes were destroyed in Shenandoah County and over seven thousand homes were damaged in Virginia”.[23]

1996 flooding in Harrisonburg, VA: Photo Credit: James Madison University; Twitter

[23] (n.d.)

Future Trends

Environmental Trends

Climate change refers to the change in average conditions such as temperature or rainfall in a region. It is natural for the climate to change over long periods of time, but human actions have caused climate change at a rate that is difficult for ecosystems and human societies to adapt to. At the end of the last Ice Age, the average global temperature increased by about 7°F over a period of about 7,000 years[24]. In the past 200 years global temperatures have increased by almost 2° F (a 900% increase in the rate of change)[25]. In Shenandoah County one of the likely outcomes of this change will be increased volatility in precipitation patterns. Warmer temperatures could lead to wetter conditions in certain areas of the county or during certain times of the year and drier conditions than normal during other times. Therefore, the county could see both more droughts and more floods in the future. Hotter temperatures also means that there is more energy in the air, which will likely lead to more extreme weather events like flash flooding and drought.

Land cover type also impacts the risk of flooding and droughts. Forests reduce the rate of flooding by:

- Intercepting rain and slowing it as it falls
- Increasing the soil infiltration rates
- Absorbing water from the soil[26]

Farmland and especially paved areas cause rainwater to flow more quickly into streams and rivers. This increases the risk of flash floods and pollution from runoff.

Much of the land in Shenandoah County is covered by land uses that have the potential to increase flooding. In the map below, land cover types that increase the risk of flooding, such as urban and agricultural land uses are shown in black and red. Land cover types that can mitigate flood risks, such as forests and wetlands are shown in light gray.

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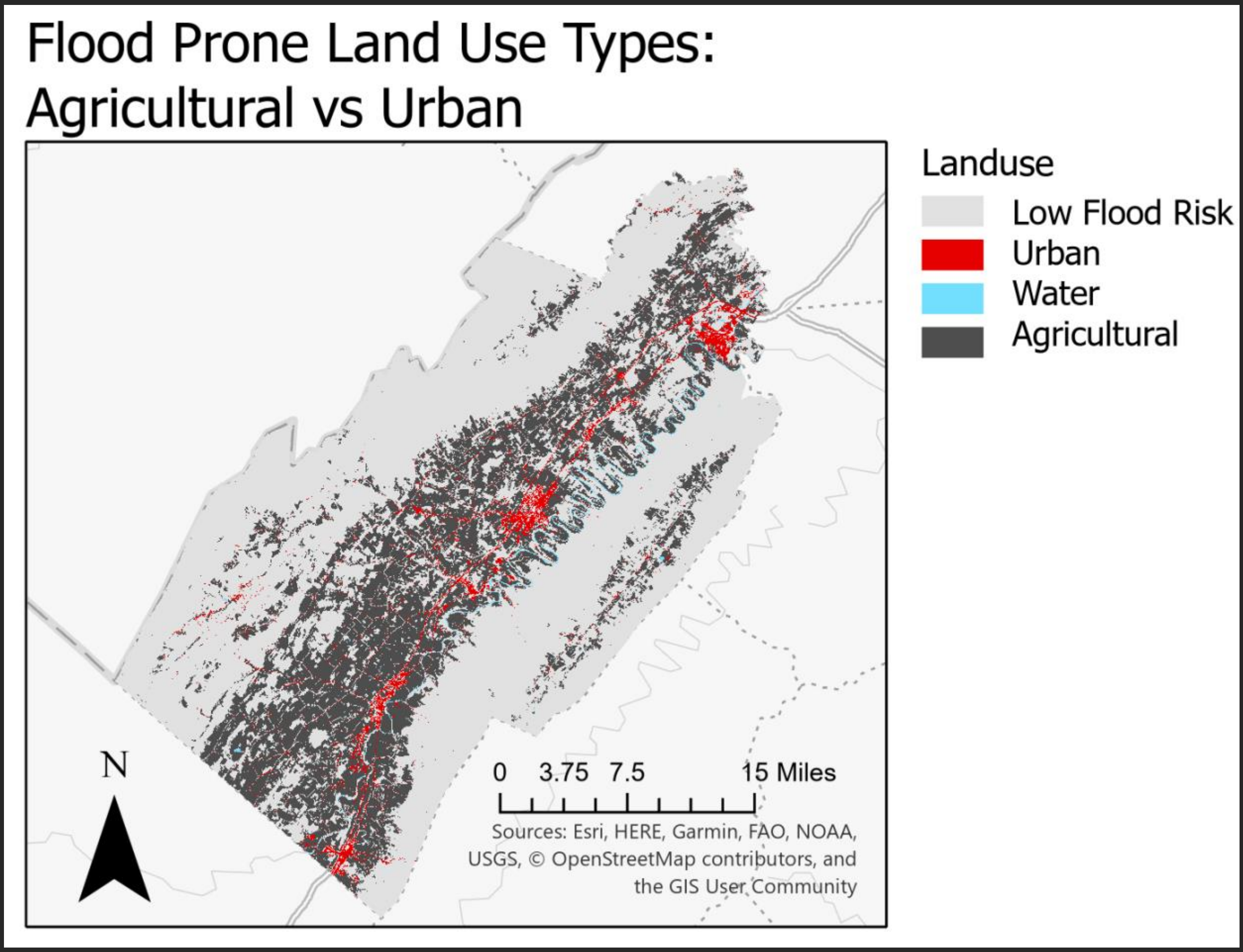
[24] The Royal Society, 2020

[25] NASA, 2021

[26] Cotrone, 2015

Between agricultural and urban land uses, urban areas tend to have more impact on the flood risk. However, given that Shenandoah County has a large amount of agricultural land, the impact that agricultural land has on flood risk will also be important to consider. The map below shows urban areas in red and agricultural areas in black. It is valuable to note that the urban areas are primarily congregated around the Shenandoah River, which likely increases their impact on flood risk.

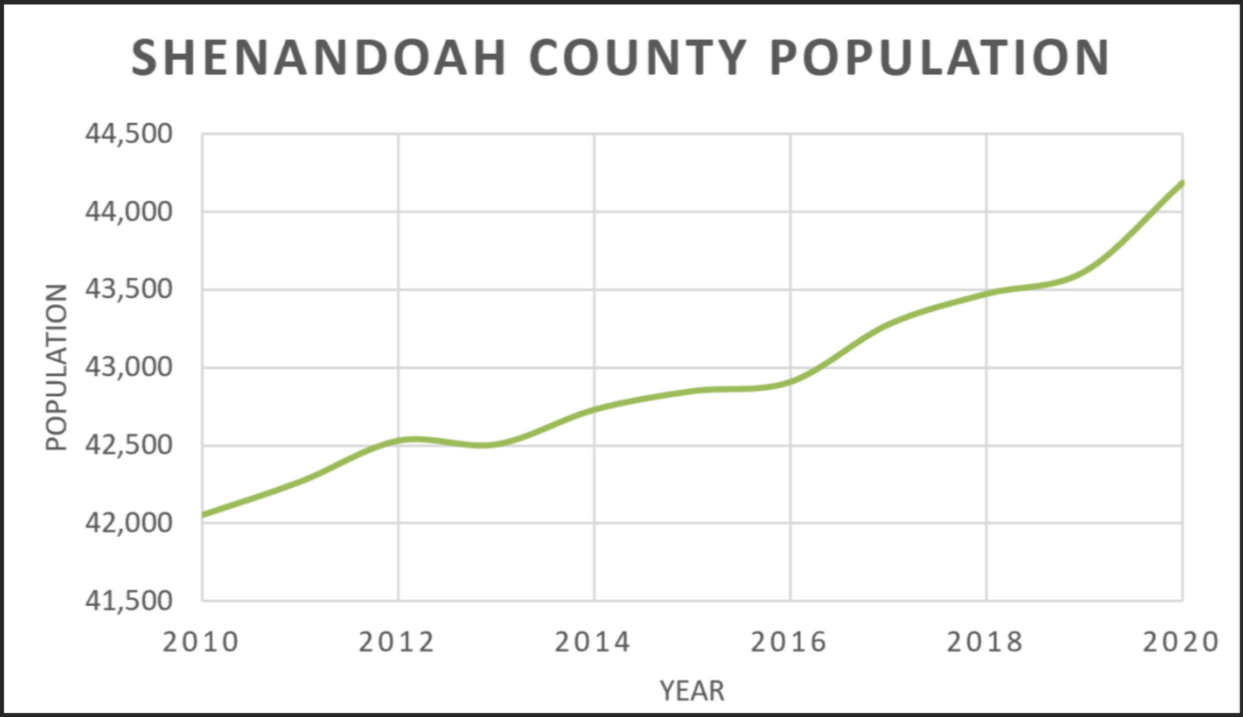


Population growth

Between 2010 and 2020, the population of Shenandoah County increased from 41,993 to 44,186; an increase of five percent[27]. This increase in population, alongside the associated growth of businesses and industries, will increase demand for water from the Shenandoah River and from the water table. As the County continues to grow economically and in terms of

[27] United States Census Bureau, 2020

population, it will be at a higher risk for drought. The infrastructure that is built to accommodate the new people and businesses also has the potential to increase the risk of flooding and algal blooms.



Data from the United States Census Bureau

Assessing Risk and Vulnerability

Background

Flood and drought risk and vulnerability are overlapping and often indeterminate concepts. In this report we have defined **risk** as a person's likelihood to experience an event such as a flood; it incorporates likelihood of climatic events, geographic location, and topography. This may also be connected to socioeconomic factors, for example, lower income people may be more likely to live in a flood prone area. Conversely, **vulnerability** is defined as a person's propensity to experience negative outcomes due to specific events such as floods. For example, people with less savings may be less able to recover from damages from drought / flood; while income / wealth is an indirect factor in determining flood risk, it plays a direct role in determining vulnerability. Under these definitions, risk focuses more on causes, while vulnerability focuses more on outcomes. This also means that risk will focus more on the physical environment, while vulnerability will focus more on socio-economic indicators. For example, assessing flood risk means looking at factors in the physical landscape and geography that make floods more likely or more severe, while assessing flood vulnerability means looking at socio-economic factors that make people less able to recover from flood costs. Unfortunately for our project we were not able to locate specific vulnerable communities within Shenandoah County both because demographic data does not exist at a granular enough scale, and because we do not have sufficient knowledge of different communities to be able to determine which are the most vulnerable. Furthermore, instead of determining a clear threshold for acceptable flood risk, we developed a prioritization pyramid for assessing flood risk to allow Shenandoah County to prioritize areas where flood risk should be reduced first, based on a vulnerability assessment. This risk prioritization spectrum includes:

1. Risk to human life as the most severe risk and thus risk to be prioritized in reduction, followed by
2. Risk to assets that are essential to human life (e.g. hospitals, grocery stores, utilities, first responders, major roads)
3. Risk to assets that are relevant to individual's livelihoods (e.g. farms, schools, industrial plants, non-essential stores, ecosystems)
4. Risk of damages to personal property above 10% of income
5. Risk of damages to personal property that is lower than 10% of income.

A key aspect of flood risk is flood hazard, which includes the probability of different magnitudes of damaging flood conditions, such as the depth of inundation, duration of inundation, velocity of moving water, quality of water, debris content of water, and the wave height in addition to still water level.[28] Reductions in any of these measurable categories can be used to measure reductions in flood risk. Although this report does not conduct a vulnerability assessment, some of the key data points that should be considered in assessing flood vulnerability are: per capita income (lower income means higher vulnerability), industry of occupation (agriculture industries are more likely to be negatively impacted by flooding, so agricultural workers would be more vulnerable), age (children and elderly are more vulnerable), disability status, poverty, housing structure (less structurally sound homes mean higher vulnerability), flood insurance status (no flood insurance means more vulnerability), and accessibility (is a property / home located on small roads that could be wiped out by floodwaters, is the property / home easily accessible to first responders).

Unlike flood risk, drought risk is less regionally variable; it is likely that everyone in Shenandoah County has a similar drought risk because they are all equally likely to experience drought based on their location. However, drought vulnerability would differ from person to person similarly to flood vulnerability. To evaluate drought vulnerability, the same criteria as proposed for flood vulnerability may be used, with the substitution of home well water access for housing structure, and the exemption of flood insurance status. In order to do a thorough flood and

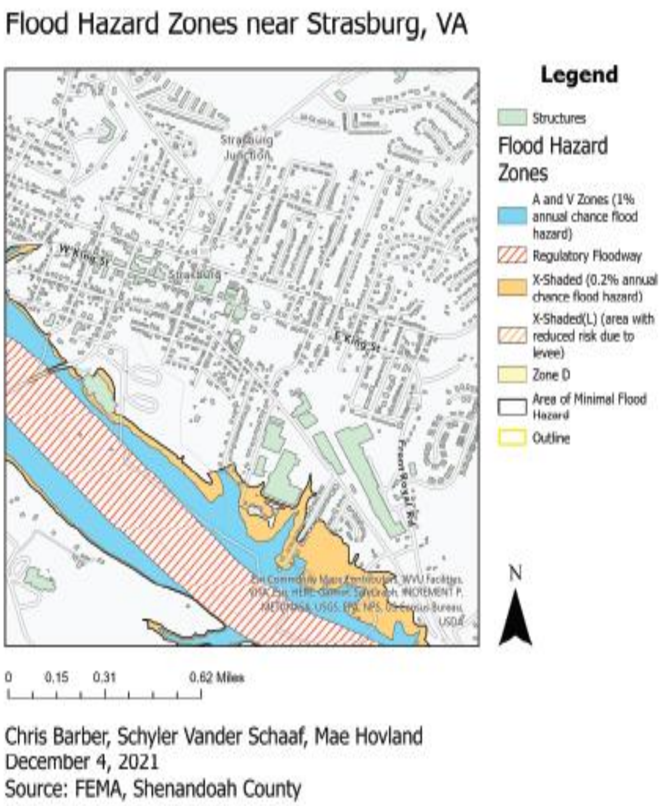
[28] National Research Council, 2015

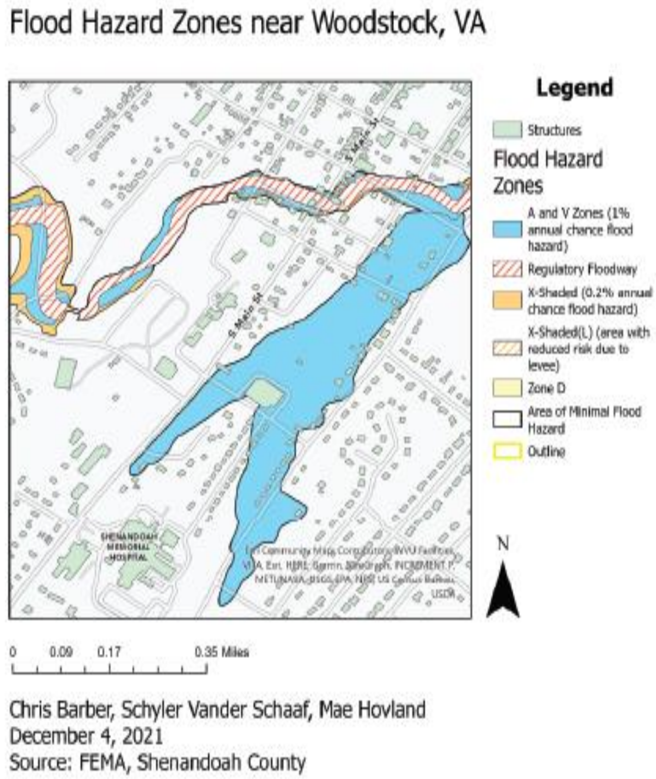
drought vulnerability assessment, these demographic data would need to be analyzed on a scale smaller than census block groups, which was not possible in this report. Once a vulnerability assessment is complete, it can be used in conjunction with the risk assessment and risk prioritization period to target specific locations for flood adaptation strategies. For example, according to our framework, a location with many structurally unsafe dwellings with high vulnerability, located within a floodplain (high risk), and thus at a reasonably high risk for loss of life in case of a flash flood should be prioritized for adaptation over a location with a newly constructed distribution warehouse, which would likely fall into the third tier of the pyramid, and have lower vulnerability.

It is important to note that neither flood risk nor vulnerability are static across time; both will change with changes in building and development, land use, weather patterns, demographic shifts, and other factors.

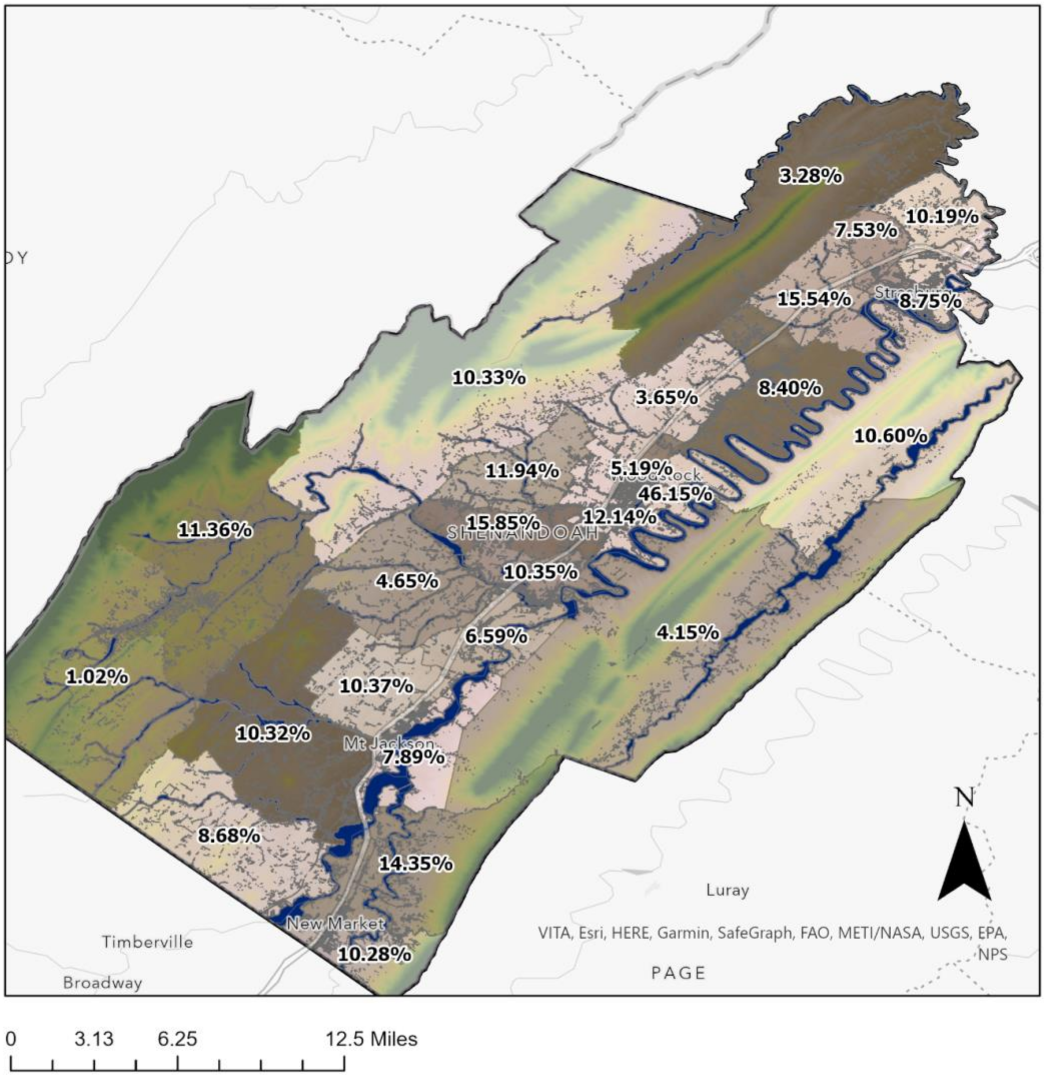
Risk Assessment

The following maps demonstrate various factors that could contribute to flood risk and vulnerability in Shenandoah County, including poverty, income, elevation, and the elderly population. They provide an idea of where flood adaptation should be begin to occur, but do not constitute a thorough risk or vulnerability assessment



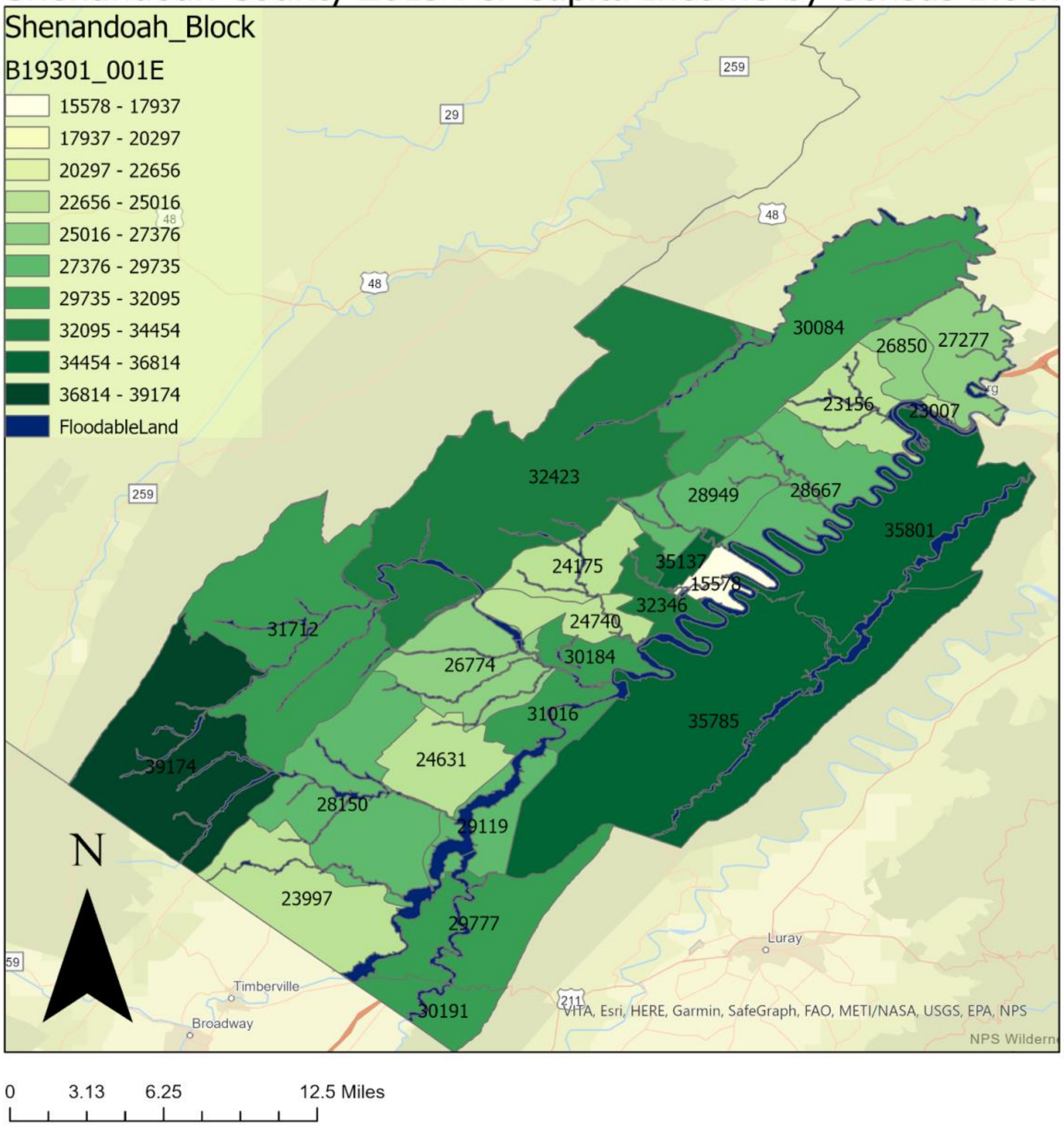


Shenandoah County Elevation and Poverty Rate by Census Block



Chris Barber, Schyler Vander Schaaf, Mae Hovland
December 4, 2021
Source: USDA, Shenandoah County

Shenandoah County 2019 Per Capita Income by Census Block



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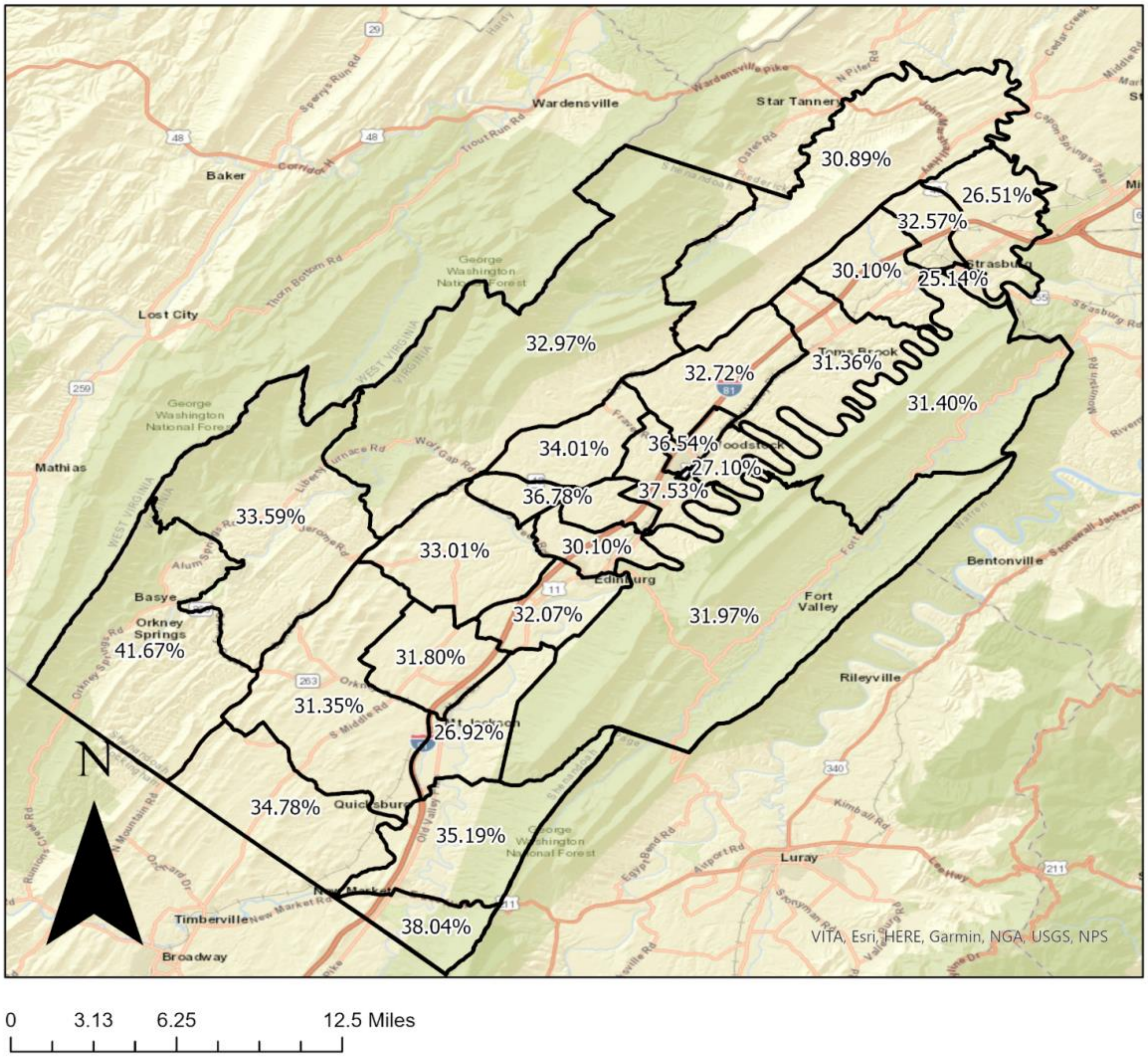
December 4, 2021

Source: American Community Survey 2019

Shenandoah County 2010 Percent of Households with Residents Over 65 by Census Block



Chris Barber, Schyler Vander Schaaf, Mae Hovland
December 4, 2021
Source: American Community Survey 2019

Stakeholder Analysis

Considered broadly enough, any actor could be considered a ‘stakeholder’ relating to flash flooding and drought in Shenandoah County. They are both public and private, organizational, and individual. Presumed stakeholders include the Virginia Department of Environmental Quality, which manages enforcement of the Chesapeake Bay Watershed Implementation Plan and its Total Maximum Daily Load (TMDL) standards; the Virginia Department of Emergency Management, which would be directly involved in flood and drought disaster events; the Northern Shenandoah Valley Regional Commission, the state-mandated planning district Shenandoah County is a member of, maintains hazard mitigation plans the county uses in tandem with its own[29]. Additionally, there is an array of civic groups who could be considered stakeholders including the Shenandoah Riverkeeper program and the Friends of the North Fork both of which focus on advocacy and conservation efforts surrounding the Shenandoah River. Commercial entities like the Massanutten Association of Realtors and the Virginia Farm Bureau could also be considered stakeholders. The latter was party to a 2011 lawsuit brought against the EPA attempting to prevent enforcement of TMDL water quality standards.

Community Outreach

Many of the recommended interventions will require buy-in from the stakeholders identified above. Therefore, community engagement and outreach efforts will be vital for Shenandoah County to successfully address flooding and drought. Two possible community outreach initiatives were identified.

One strategy involves a research farm run by Virginia Tech. Currently, farmers are able to visit the farm to learn about the environmental best practices being developed there. The impact of this resource could be increased by developing online videos or sharing information about the farm on a local news segment.

Another existing community engagement strategy that could be expanded upon is the Shenandoah 2045 "Postcards from the Future" campaign. Residents could send flooding or drought themed postcards to each other to encourage residents to reduce their water usage or invest in flood mitigation strategies.

[29] Northern Shenandoah Valley Regional Commission, 2018

Case Studies and Recommendations

Municipalities have a vested interest in stormwater management for numerous reasons including flood mitigation planning, pollution reduction, ecological preservation, and overall public health concerns. It is considered to be "one of the biggest and most expensive problems facing cities across the United States".[30] Stormwater and retention strategies can generally be considered in the context of their intended purposes - residential, commercial, or public. Additionally, stormwater best management practices (BMPs) need to be tailored to the unique needs of urban and rural settings. While many common strategies like rain barrels, bioswales, rain gardens, and other "green" infrastructure have wide applications across a variety of environments, stormwater management and retention in an agricultural context is an emerging and evolving field of research. The following case studies illustrate a few pertinent strategies with potential applications for Shenandoah County.

Rose River Restoration, Madison County, VA

Similar to the South Fork of the Shenandoah River, the Rose River is in a mountainous agricultural area. The Rose River is much smaller than the South Fork of the Shenandoah River, with a watershed of 14 square miles, as opposed to Shenandoah's 1650 square miles. However, some of the flood and drought management best practices that were effective for the Rose River can also be implemented by Shenandoah County, either in the Shenandoah River itself, or one of its tributaries.

Prior to restoration by the US Department of Agriculture and the Natural Resources Conservation Service, the quality of the Rose River had been damaged by several large floods. If the river had not been restored, a nearby road would likely have been undercut, high rates of sedimentation would have continued to harm fish habitats, and large cobble and debris in the river would have created a higher risk for flooding. The main goals of the restoration were to repair the hydraulic functions of the river, specifically by increasing the depth of the river to its natural extent. Some secondary goals that were identified included public safety, increasing habitat for stocked trout, and protecting nearby infrastructure. The total cost of this project was $120,000, or $29 per linear foot[31].

[30] Copeland, 2014

[31] Federal Emergency Management Agency, 2017

The restoration strategies used for the Rose River included:

Sediment Deposit Removal

Built up sediment causes the riverbed to become shallower and wider. This can lead to flooding in areas that didn't used to be in a floodplain. Sediment can be removed from rivers and streams through strategies such as dredging.

Vortex Rock Weirs

Vortex rock weirs consist of stones arranged in a 'V' or 'U' shape pointing upstream. The sides of the weir must be wide enough that the water is directed over and through the wier, rather than around it. Weirs slow the flow of water and work to prevent erosion which can negatively impact the quality of the water and the risk of flooding. They are especially effective in relatively long sloping waterways such as ditches along sloped roads or waterways through sloped crop fields. The cost of labor and machinery needed to install a vortex rock weir can be relatively expensive, but they are long term solutions to erosion and they can benefit farms by protecting valuable topsoil from erosion[32].

Rootward Revetments

A rootward is the lower trunk and roots of a large fallen tree. In a rootward revetment, the rootward is placed with the trunk buried into the riverbank and the roots facing into the river. These revetments help increase habitat for fish and insects. They also increase the velocity of a river, allowing sediments to flush out. Rootward from downed trees can be used to create rootward revetments, meaning the cost of this strategy can be as little as simply the cost of labor. Revetments are best used in meandering streams that often overflow their banks, and have fish habitat deficiencies. The placement of rootward is vital for their effectiveness, so it is vital to consult a professional river engineer before installation. Furthermore, since the riverbank may be altered by installation, a permit may be required[33].

Riprap

Riprap is a permanent layer of angular rocks that line the sides of a stream or river. It is used to slow the speed of water and reduce the risk of erosion and undercutting. It is most effective at the outlets of storm pipes, bridges, steep slopes, along ditches, and other areas where

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[32] Porter, 2017

[33] Stream Water Center

concentrated runoff is likely. It is normally used in areas where vegetation is unable to grow, such as areas with high water velocity. In areas that can support vegetation growth, that may be a better alternative, as vegetation is often cheaper and can provide other benefits such as habitat regeneration and pollution removal. Riprap is also less effective in areas where the slope is greater than 2:1, as it can become unstable. However, in general, riprap is a cheap, simple, and effective tool to prevent erosion[34].

Tree Installation in Riparian Zone

Trees planted near streams and rivers can have a major impact on water quality, flooding and erosion. Trees increase the infiltration capacity of the soil, absorb, and slow the flow of surface water, filter out sediment such as nitrogen, and allow remaining sediment to settle.

Challenges, Feasibility, and Applications in Shenandoah County

These steam interventions could easily be applied to streams in Shenandoah County. However, the impact of these strategies is likely to be relatively local and small scale. Therefore, it would be beneficial to combine the best practices from this case study with those from other case studies in order to benefit all areas of Shenandoah County.

Agricultural water management best practices from Tahara, Victoria, Australia

The climate conditions in Tahara, Australia are relatively similar to that in Shenandoah County, Virginia; with average temperatures ranging from 40 to 70 degrees Fahrenheit, and rainfall averaging at around 70 inches (compared to Shenandoah County's 40 inches). Given these similarities, several water management best practices can be taken from a Taharan cattle farmer, Bill Stonnill. Stonnill practices a 'whole farm approach to water', which uses strategies in different areas of farm management to preserve water and protect water quality[35].

Rotational Grazing

One such strategy is rotational grazing. Stonnill's farm has almost 40 paddocks, and cattle are rotated between each one, for up to three days at a time. A crucial aspect of this strategy is

[34] Rodriguez, 2021

[35] Agriculture Victoria, 2021

that each paddock is allowed to rest for at least 60 days between periods of grazing. This increases the pasture cover and plant biodiversity and allows time for deep rooted perennials to grow. This groundcover reduces water runoff, which in turn reduces the risk of drought and agricultural pollution from runoff. In low water periods, the required rest period may be as much as 120 days, to ensure that this vital groundcover is preserved. This system of rotational grazing ensures that the cattle have adequate plants to graze on with minimal impact to the land and water.

Trough Watering

Another strategy used on Stonnill's farm is the use of troughs for watering cattle, rather than allowing them to drink directly from the water source (in this case a river). Stonnill achieves this by pumping water with an air compressor from the river to storage tanks uphill from the river. Gravity then pulls the water back down the hill into the troughs. The farm only requires seven throughs to service all 40 paddocks. This is done by arranging the paddocks like a wagon wheel around the water stations. The pump is capable of delivering 300 gallons per hour, which is calculated to prevent the cattle from emptying the troughs and becoming stressed. The system, including the troughs, pump, air compressor, and water and air pipes, cost around 7,000 USD to install. According to Stonnill, this system has made life easier; "it's a very easy farm to run and takes very little time to run it." The water system also benefits the water quality of the river, which is incredibly important as Stonnill's main source of water. If cattle have access to the river they can quickly contaminate it and cause erosion by eating the plants along the bank. Therefore, using water troughs protects the quality of the farm's main water source, while also making it easier to implement rotational grazing.

Challenges, Feasibility, and Applications in Shenandoah County

Since these flood and drought mitigation strategies rely on the decisions of individual farmers, these best practices may be difficult to implement. According to a study of aerial photos conducted by the Environmental Integrity Project, 81% of farms fail to fence their cattle out of streams[36]. However, there may soon be a requirement for farmers to make these changes. A recent bill from the Virginia government sets 2025 as the target date for the state to meet the water quality goals determined by the Chesapeake Bay watershed implementation plan. If it is determined that those goals have not been met due to agricultural mismanagement, certain requirements will go into effect, including a requirement for cattle exclusion from streams[37].

[36] Environmental Integrity Project, 2019

[37] House Bill 1422, 2020

Whether or not cattle exclusion becomes mandatory, Shenandoah County could encourage farmers to implement the strategy through education, resources, and incentives.

On-Farm Water Storage Systems

Mississippi State University advocates for the use of On-Farm Water Storage systems (OFWS).[38] These relatively simple systems capture rainwater and runoff from furrow irrigation and "can be constructed with only a storage pond, with an enlarged tailwater recovery (TWR) ditch, or with a TWR ditch and a storage pond". However, while these systems are popular in Mississippi where drilling for groundwater is prohibitively expensive and often impractical, they may not be appropriate for agricultural operations where groundwater is more accessible.

Integrated Stormwater Retention System

In West Sonoma County, California, the Occidental Arts & Ecology Center (OAEC) has developed an Integrated Stormwater Retention System in 2011 which "demonstrates a rural residential approach to integrated stormwater management that moves away from drainage-based solutions and towards retainage-based solutions that also promote increased biodiversity."[39]

Aquifer Storage and Recovery

Introduction

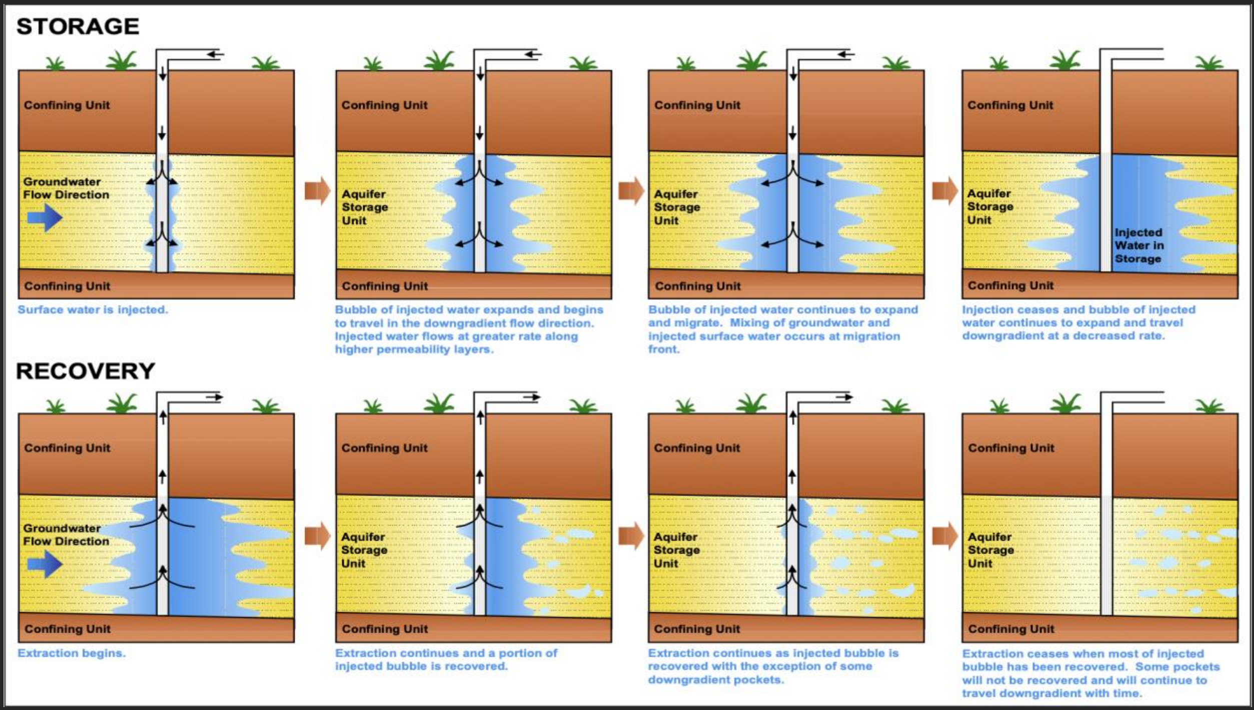
Aquifer Storage and Recovery (ASR) is a flood and drought management strategy that involves taking surface water when it is abundant (such as after a flood) and storing it in subsurface aquifers for later use. ASR consists of three phases: surface water injection, storage, and extraction.[40] The first phase involves injecting treated surface water through a well and storing it in a confined aquifer. During the injection phase, surface water travels away from the injection well in a radial fashion, displacing the existing groundwater and forming an irregular column of injected water around the well; the longer the injection period, the wider the column

[38] Tagert, 2021

[39] Dolman and Lundquist, 2013

[40] FEMA, 2017

of injected water. During the storage phase the rate and direction of groundwater movement is controlled by the natural groundwater gradient and hydraulic conductivity of the formation, and is generally very slow. During the water extraction phase, the injected column of surface water is recovered, treated, and utilized as a freshwater supply, and the diameter of the column is reduced. ASR systems can be operated such that the recovered water is used to satisfy seasonal demands, or water can be stored over several years, recovering only a portion of the water but leaving a significant quantity of stored water to meet demands during drought conditions.



ASR provides all of the benefits of a surface reservoir in terms of water storage, but does not have evaporative or seepage losses, provides better protection of the injected water quality than a surface reservoir, eliminates the potential for levee failure and downstream catastrophic flooding that can occur with surface reservoirs, helps recharge aquifers and prevent land subsidence, and preserves surface cover for other uses.[41] Additionally, ASR systems are more resilient and better able to mitigate the effects of climate change than alternative and more traditional storage technologies because the stored water in an ASR system is protected from potential pollution from atmospheric deposition, animals, and protected during extreme weather conditions such as droughts and hurricanes.[42]

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[41] Federal Emergency Management Agency, 2017

[42] Federal Emergency Management Agency, 2017

While ASR alone does not typically provide flood hazard reduction independently due to the relatively low injection volumes (compared to flood flows), it can be used to free up storage in regional stormwater management facilities and reservoirs if pumped at a constant maximum rate. Because of its long-term drought adaptation potential, ASR systems, though still relatively uncommon, are becoming more popular across the country as places that were not previously susceptible prepare for future uncertainty under climate change conditions. According to a 2013 survey of the status of ASR in the U.S., over 50 sites in at least 26 states have either used or investigated the use of ASR, and worldwide, there are over 100 operational ASR facilities.[43]

ASR Case Studies

Case Study 1: Pitt County, North Carolina[44]

Pitt County developed North Carolina's first ASR system with the goal of storing seasonal excess treated drinking water obtained from the Tar River Treatment Plant located in Rocky Mount, NC (less than an hour from Greenville, NC). Pitt county obtains more than 90% of its water from the Tar River and was worried about overdrawing. The Greenville storage aquifer is made of unconsolidated sand deposits within the Cretaceous Aquifer System. To date, the ASR facility has been completed and cycle testing has begun; eight 500 foot wells have been constructed which can produce up to 8 million gallons of water per day. In times of lower need, treated drinking water can be stored; this allowed the Greenville Utilities Commission to meet peak demands during the summertime, meaning there is no need to expand the water treatment plant to cope with increased summer demand.

Before operation of the ASR system could begin, there were several permitting requirements for Pitt County. From the Division of Environmental Health they needed approval to operate a public water supply system in North Carolina and needed to meet drinking water standards before any water (from the ASR system) could be distributed. From the Division of Water Quality they needed approval for construction/operation of injection wells and needed to meet groundwater quality standards. Finally, from the Division of Water Resources Must the county needed to obtain approval to withdraw equal or lesser amounts of stored water if the ASR facility was operating in Capacity Use Area, as established by the Water Use Act of 1967. The project timeline was as follows:

[43] Federal Emergency Management Agency, 2017

[44] Campbell, 2014

- ➔ 1995 – Initial Discussion.
- ➔ 1997-1998 – Study and Site Selection.
- ➔ 1999-2000 – Department of Environmental and Natural Resources (NCDENR) approved to build TW-1 well. TW-1 was the original idea, but regulatory issues occurred.
- ➔ 2001-2002 – 2 monitoring wells installed and satisfied Underground Injection Control (UIC).
- ➔ 2003-2004 – DENR (Department of Environment and Natural Resources) approved ASR-1 well to be installed. ASR-1 was constructed.
- ➔ 2006 – A new consultant helped to redesign the ASR system, ultimately reducing costs.
- ➔ 2007 – Greenville Utilities Commision obtained external funding for the project.
- ➔ 2008 – TW-1 well is used as a "recovery-only" component of ASR-1.
- ➔ 2010 – Completion of well construction almost completed.
- ➔ 2011 – Completed 8 months of cycle testing and final regulatory approvals obtained to operate the project.

Initial cost for the well infrastructure was estimated to be $1.5 million. Pitt County received $703,000 in grants from the US Department of Commerce – Economic Development Administration, and $500,000 from NC Rural Center. The main benefits reported were: peak shaving, increased water security, increased system reliability (low cost and long term water storage), an additional 200 million gallons of ASR storage capacity at capital cost of $0.01/gallon, ground storage at capital cost of $1.00/gallon, and elevated storage at capital cost of $2.50/gallon. The final costs reported by Pitt County were: operation and maintenance on existing wells (excluding electrical costs) - $7,500/well/year or $0.43/1,000 gallons; injection costs of $0.085/1,000 gallons in the summer and $0.065/1,000 gallons in the winter, and recovery costs of $0.30/1,000 gallons.

Case Study 2: Roseville, California

Roseville implemented an ASR system in 2004 primarily as a drought adaptation strategy. The long-term goal of the City of Roseville was to operate a network of 13 dual purpose ASR wells (wells used for both injection and extraction) which cumulatively are capable of injecting

10,000 acre-feet of water per year. The overarching purpose of the ASR system is to store treated surface water from Folsom Lake in the groundwater basin underlying Placer County by direct injection during wet years for extraction to supplement the City's surface water supply during dry years.[45]

Roseville conducted extensive pilot testing to determine the impacts of ASR on existing and injected ground water quality. The Phase I ASR pilot test was performed at the Diamond Creek Well from May 5 to September 20, 2004. Cycle testing was conducted using potable water that originated in the Sierra Nevada, flowed into the American River watershed, and was stored in Folsom Lake. The city conveys all of its surface water to its water treatment plant for treatment to drinking water standards. During the cycle test, this potable (treated) water was conveyed to the Diamond Creek Well through the City's drinking water infrastructure, and injected into the aquifer (the Mehrten formation) to evaluate the overall technical feasibility of ASR at the site.[46]

Baseline monitoring and sampling included a series of monitoring and sampling events performed from May 5 to June 16, 2004. During this period, no water was injected at the Diamond Creek Well. The purpose of baseline monitoring and sampling was to establish the groundwater elevations and water quality in the aquifer before injecting the aquifer with treated water. The injection portion of the cycle test consisted of 26 days of continuous surface water injection followed by two days of rest, or storage. The total volume of water injected was 158 acre-feet (51,500,000 gallons).[47] The injection portion of the cycle test included four monitoring and sampling events, performed from June 16 through July 12, 2004, to determine changes in groundwater elevations and water quality of the aquifer, at various distances from the injection well. System pressure and injection flow rate were also monitored during the injection phase of the pilot test. There were three extraction phases during the study: July 14 through 26, August 3 through 9, and September 9 through 20, 2004. The three extraction phases were separated by storage periods lasting 8 and 31 days.[48] The total volume of water extracted during all three phases was 439 acre-feet (143,000,000 gallons), representing 278 percent of injected water volume. The volume extracted substantially exceeded that injected to ensure that all the injected water was removed from the aquifer. Eleven monitoring and sampling events were conducted at the Diamond Creek Well and six monitoring and sampling events were conducted at the three monitoring wells to determine changes in groundwater

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[45] Report Published by the University of Minnesota, 2020

[46] Report Published by the University of Minnesota, 2020

[47] Petersen and Glotzbach

[48] Petersen and Glotzbach

elevations and water quality of the aquifer, at various distances from the injection well, during and following the extraction period.[49]

No appreciable contamination was observed in the recovered water in the pilot study, except for disinfection byproducts (DBPs) consisting of trihalomethanes (THMs) and halo acetic acids (HAAs), which occurred at levels below their respective maximum contaminant limits (MCLs). For this reason, the Central Valley Regional Water Quality Control Board advocated for the complete removal of even trace concentrations of DBPs before injection into the groundwater aquifer. A second pilot study was conducted at a much larger scale and occurred over a longer time period from December 2005 to February 2008. A total of 830 acre-feet (270 million gallons) of treated drinking water was injected over a 142-day period, which was followed by a 407-day storage window, and the subsequent withdrawal of 2,140 acre-feet (697 million gallons) which was delivered to customers.[50] Water quality parameters observed over the course of the second pilot study demonstrated that injection of drinking water into the aquifer beneath the City of Roseville was not likely to cause exceedances of water quality parameters above California Water Quality Objectives. In addition, the results of the pilot studies indicated that many water quality parameters within the context of the storage area would improve as the result of injecting surface water with a lower total dissolved solid load into the groundwater aquifer.[51]

Challenges, Feasibility, and Applications in Shenandoah County

Some of the challenges for implementing ASR include reduced recovery efficiency due to improper selection of the storage zone, arsenic leaching from the storage zone, and elevated arsenic concentrations in the recovered water. However, proper hydrogeologic assessment can reduce many of these risks. In Shenandoah County specifically, arsenic leaching will be a risk. Arsenic is commonly part of a naturally occurring mineral called pyrite in many unconfined and confined aquifers. Under natural conditions, groundwater exists under reduced conditions, and arsenic is bound up in the pyrite matrix. However, potable water, partially treated surface water, and reclaimed water are typically highly oxidized due to the treatment and disinfection

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[49] Petersen and Glotzbach

[50] Petersen and Glotzbach

[51] Report Published by the University of Minnesota, 2020

process.[52] When these waters are injected into aquifers and pyrite is present, arsenic is released into the stored water, and when recovered, the arsenic concentrations are sometimes elevated, exceeding the drinking water limit of 10 micrograms per liter. If the recovered water has elevated arsenic concentrations, the recovered water can be blended with a secondary source (potable water or reclaimed water) to meet the regulatory limit for arsenic prior to using the water. Thus, while arsenic leaching is certainly a concern, it is not necessarily a barrier to ASR use. In order to confirm favorable hydrogeology of a site, an exploratory test well should be drilled.[53] ASR facilities should also be sited to avoid sensitive fish and wildlife and designated critical habitats, thereby reducing potential impacts and the necessary level of EHP review.

The quality of the source water to be injected (finished water, raw groundwater, untreated or partially treated surface water, or reclaimed water) influences the technical considerations for an ASR project. For most ASR projects, either finished treated water, untreated, or partially treated surface water is injected into a brackish groundwater aquifer above the underground source of drinking water. For ASR projects injecting above the USDW, the goal is to store and recover the injected fluid with minimal mixing with native groundwater; in this case there must be good hydrogeological confinement above and below the target storage zone to minimize vertical flow and very little mixing between injected water and existing groundwater.[54] All recharge or injection of fluids directly into aquifers in the U.S. are regulated by the USEPA under 40 CFR Part 144 titled Underground Injection Control (UIC) Program. As part of the USEPA UIC permit process, an applicant must demonstrate that the activity does not impact other users of the aquifer.

Since ASR is often considered a sustainable, environmentally friendly, alternative water supply option, there are currently several Federal programs that have or could potentially fund ASR projects such as U.S. Bureau of Reclamation, U.S. Environmental Protection Agency (USEPA), U.S. Army Corps of Engineers (USACE), U.S. Department of Agriculture (USDA), and U.S. Department of Housing and Urban Development (USHUD).

Within Shenandoah County, ASR could be a key drought preparedness and flood risk reduction strategy. On average, of the approximately 36 inches of precipitation per year in Shenandoah County, 4” infiltrates the soil and eventually recharges the groundwater supply.[55] The rest either evaporates back into the atmosphere or runs into streams which feed the North Fork of

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[52] Federal Emergency Management Agency, 2017

[53] Federal Emergency Management Agency, 2017

[54] Federal Emergency Management Agency, 2017

[55] Natural Resources, 2014

the Shenandoah River. Implementing an ASR system would enable the county to preserve more precipitation for use during drought conditions and could help prevent flash flooding if current water storage facilities could be partially converted into temporary flood-water diversion sites. As for the hydrogeologic suitability of Shenandoah County, approximately 30% of county land, concentrated in the central valley area, overlies carbonate rock, primarily limestone. This bedrock material is characterized by numerous caves and caverns, sinkholes, underground solution channels, and fractionated layers.[56] When these conditions are present the term karst is applied. Groundwater in karst terrain is noted for easy entry from surface water sources, which would make it easy to inject water into an ASR system. However, karst also has quite rapid lateral movement, and hence susceptibility to contamination which can spread rapidly over large underground areas. Thus, for an ASR system to be successfully implemented a site would need to be chosen that has very good existing ground water quality (and good injection water quality), or a site with significant limiting layers to prevent groundwater glow away from the injection well.

In 2001 a Regional Water Supply Committee study (Northern Shenandoah Valley Regional Partnership) forecast that by 2025 the maximum daily demand for water from the North Fork would exceed the low mean flow of record supply of water. This highlights the need for more water storage and drought preparedness in Shenandoah County. Currently, nine dams temporarily impound the flows of seven county streams resulting in a potential maximum storage of approximately 1800 million gallons.[57] This existing infrastructure could be used to collect water (especially excess flows and floodwater) to be injected into ASR systems, freeing up surface reservoirs to better handle flash flood waters.

While ASR does pose risks in terms of potential groundwater contamination, it presents a promising option for Shenandoah County to more safely store excess water for times of drought.

[56] Natural Resources, 2014

[57] Natural Resources, 2014

Conclusion

This report presents findings on the general risks associated with flash flood and drought, the history of flash flood and drought in Shenandoah County, a framework for, and early analysis of, flash flood and drought risk and vulnerability, and an analysis of existing flash flood and drought mitigation and adaptation case studies and descriptions of specific strategies. While flash flood and drought risks are ever changing, the strategies presented constitute a diverse approach to managing risk for consideration in Shenandoah County. Further research is needed to determine specific locations of acute flood risk and vulnerability, and we recommend a full vulnerability assessment be carried out once adequate demographic data for the county is collected. Further areas of research of interest to the project are the collection and digitization of well location data, as well as groundwater / aquifer location, quality, and abundance data. Other strategies not mentioned in this report, but which might merit further research for application in Shenandoah County include green infrastructure / low-impact development. We hope this report will be useful to Shenandoah County planners and stakeholders as they plan for a more resilient future in the face of climate change.

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