Drought in the Shenandoah Valley

A capstone report submitted to the

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Abstract

Drought represents a significant and persistent natural hazard, particularly in regions heavily dependent on agriculture. This report will focus on the agricultural impacts of drought in the Shenandoah Valley in Virginia. This capstone project explored the multifaceted impacts of drought on agriculture in this region, emphasizing the cascading impacts on the environment, economics, government, and society. Drought not only diminishes crop yields but also impacts economic stability and soil health, thereby affecting not just the agricultural sector but the broader community as well. A stakeholder analysis was conducted to provide a detailed understanding of drought and the complex interrelationships between drought conditions and agricultural productivity. The project solution involved developing an information dashboard and map to visually represent the severity of drought impacts on local agriculture. This tool aims to offer farmers and community members actionable insights to better prepare for and mitigate the effects of drought, thereby enhancing their resilience and economic stability. The project integrates scientific research with community input to address the pressing challenge of drought, ensuring that the strategies developed are both scientifically sound and tailored to the needs of the local population.

1.0 Project Motivation

The Shenandoah Valley has experienced significant drought events throughout its recorded history, including a devastating period during the Dust Bowl of the 1930s. Over the past century, recurring droughts have continued to pose challenges to the region's agricultural and ecological resilience. Today, the potential increasing threat of climate change and the intensification of natural disasters (Smith et al., 2025) further amplify these concerns. This has been especially evident in the Valley over the past two years, with two recent episodes of extreme drought occurring from October 2023 to January 2024, peak seen in Figure 1, and again from June to October 2024.

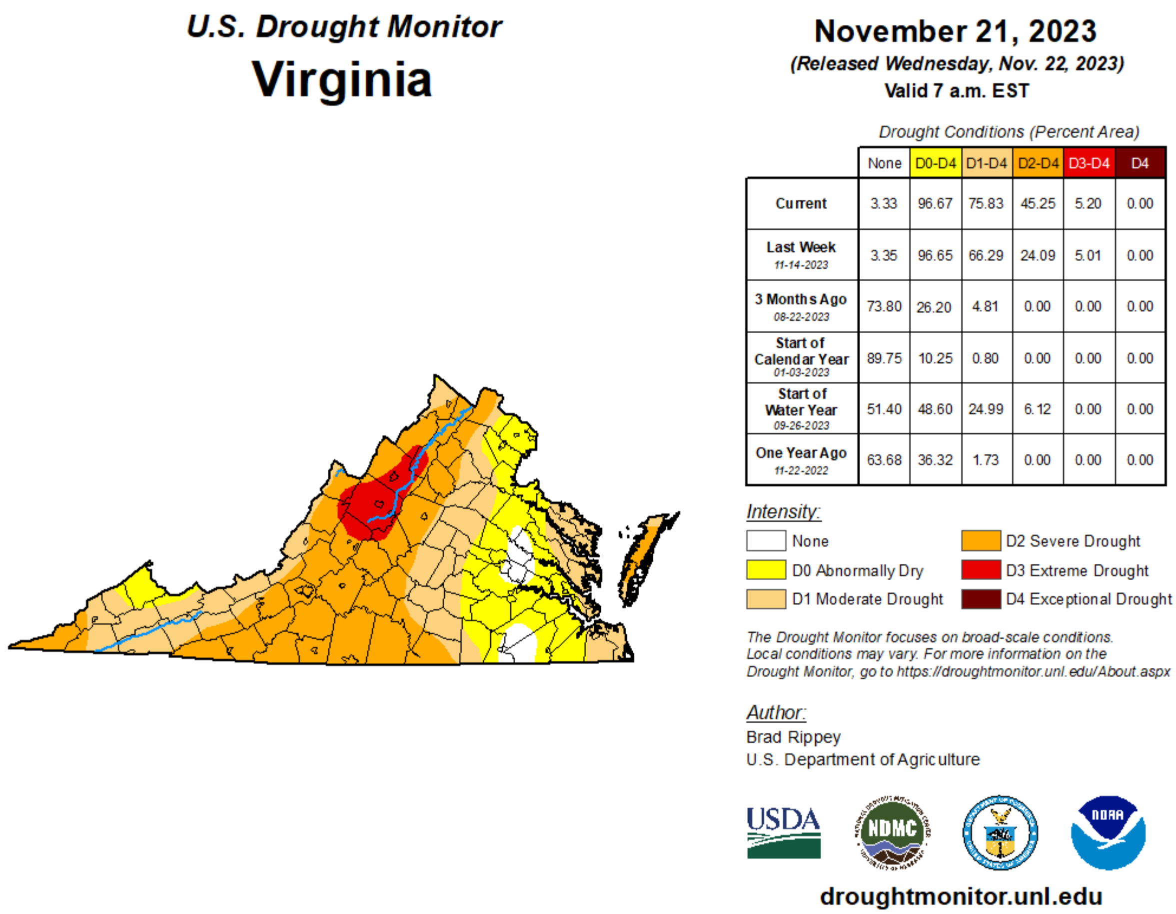

Figure 1: Peak of the 2023 Drought, most of Rockingham and Augusta County in extreme drought and the rest of the Valley in severe.

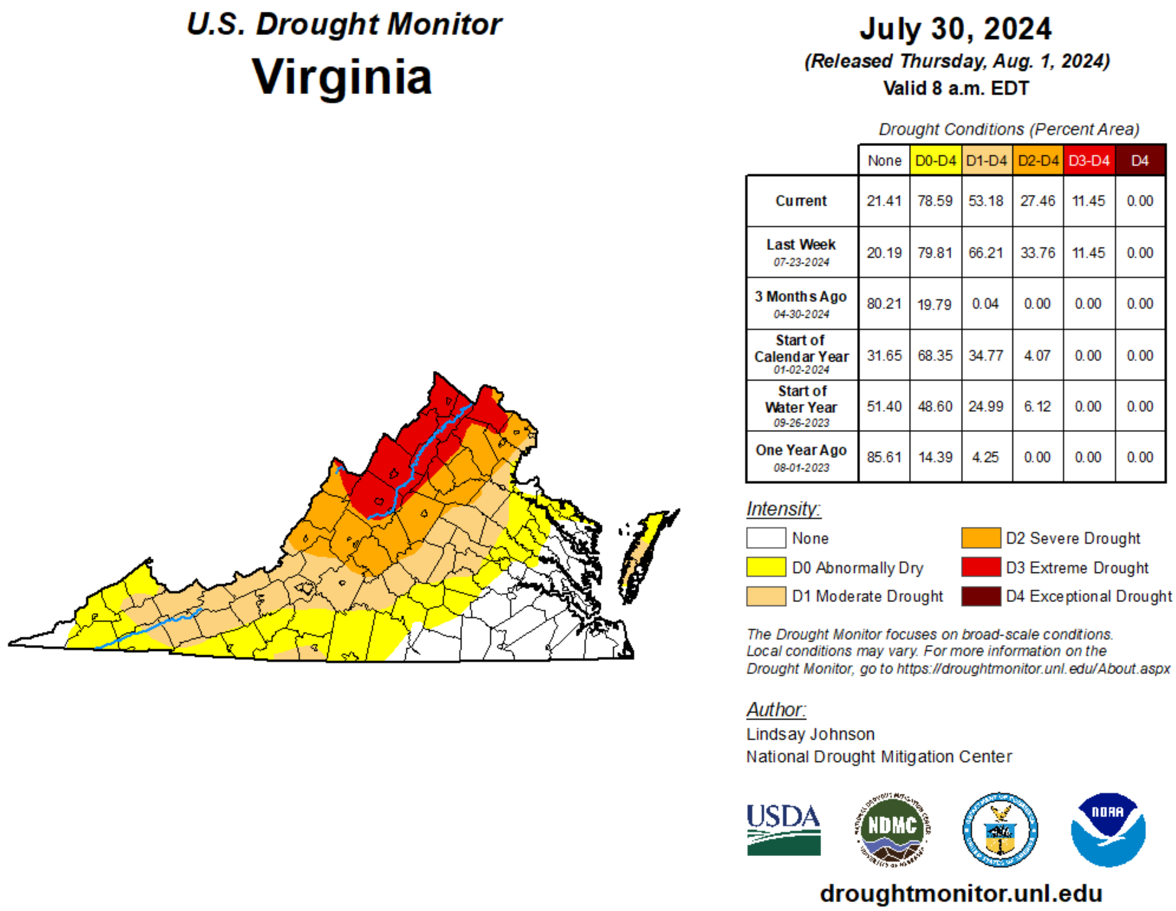

Figure 2: Summer Drought of 2023, almost all of the Valley stayed in extreme conditions for about 3 weeks from July 16th to August 6th

These events—and the firsthand experience of their impacts—have motivated the development of this project. Coursework completed in the ISAT Program at JMU allowed firsthand experiences of the effects of drought from ISAT 320, by completing soil health analysis on the ISAT Hillside during October 2023 and then North River Water Analysis in the November, which saw very low water levels and streamflow. By combining environmental science principles with computing tools and stakeholder analysis, this work seeks to provide both practical, ground-level insights and a data-driven understanding of drought dynamics. The goal is to inform more effective preparation, mitigation, and response strategies for the Valley, while also understanding the climate and local weather patterns and data that are attributed to drought.

1.1 Introduction

Drought, a complex natural disaster driven by climate variability and human activities, poses significant challenges to agricultural regions like the Shenandoah Valley, Virginia. With growing public awareness of global climate change and its potential impacts, concerns about the frequency and severity of drought events have intensified. As a result, understanding the interactions between drought and agriculture becomes imperative for developing effective adaptation and mitigation strategies.

The Shenandoah Valley, despite its favorable climate conditions, experiences periods of prolonged precipitation deficits, leading to diminished crop yields, economic losses, and environmental degradation in the agricultural sector. Drought impacts extend beyond the agricultural sector, affecting various facets of the community and economy. Reduced agricultural production results in increased food prices, disrupting household budgets and consumer purchasing power. Businesses reliant on agricultural inputs may face supply chain disruptions and operational challenges, leading to economic uncertainties.

Addressing drought in regions like the Shenandoah Valley offers numerous benefits, particularly in safeguarding agricultural productivity and enhancing community resilience, such as through drought planning to effectively manage water resources among a community (Novini, 2023). Proactive mitigation efforts empower communities to minimize economic losses during drought periods and foster greater social cohesion and stability.

Furthermore, understanding the interactions between agriculture and drought is essential for developing effective adaptation strategies. By understanding how severity of drought can affect agriculture, stakeholders can anticipate and prepare for drought events, minimizing their impacts on agriculture, water resources, and the broader environment. Ultimately, addressing drought in the Shenandoah Valley and similar regions promotes sustainable development and resilience in the face of climate variability, ensuring the well-being of present and future generations.

1.2 Problem Statement

This project analyzes the potential severity of drought in the Shenandoah Valley and its impact on agriculture in the region. This project will be informed by a stakeholder analysis involving agricultural producers, professors, governmental & extension agents. Our project resulted in the design of a prototype information dashboard and map to improve understanding of how drought affects the region and illustrate the relationship between agricultural impacts, drought severity, and climate data. The dashboard will serve as a decision-support tool for agricultural producers, as well as an educational tool for producers and the broader community.

2. Background

2.1 What is Drought?

Drought is "a prolonged dry period in the natural climate cycle that can occur anywhere in the world. It is a slow onset phenomenon caused by a lack of rainfall. Compounding factors, such as poverty and inappropriate land use, increase vulnerability to drought," defined from the World Meteorological Organization (WMO). Drought is a climatic phenomenon driven by temperature and precipitation dynamics and is an inevitable consequence of climate's natural variability. However, drought is not solely a result of moisture deficits; it is also influenced by a complex interplay of natural precipitation deficiencies, human water demand, and inefficiencies in water distribution and usage. Drought can persist for multiple seasons or years, inflicting widespread impacts on water resources, economy, environment, and society.

Climate dynamics and variability play a crucial role in the formation and cessation of droughts, with persistent weather patterns often creating favorable conditions for their development. One of the most influential climate drivers for drought prediction is the El Niño–Southern Oscillation (ENSO), which affects global weather patterns. Other climate drivers, such as land-atmosphere feedback, the Pacific Decadal Oscillation (PDO), the Atlantic Multi-decadal Oscillation (AMO), and the Indian Ocean Dipole (IOD), also influence drought progression across North America. However, anthropogenic climate change may alter the impact of ENSO and other climate drivers on drought dynamics, although the exact nature of these changes remains uncertain. (Parker, 2023)

"Climate change has further altered the natural pattern of droughts, making them more frequent, longer, and more severe" (U.S. Geological Survey) This is due to multiple varied reasons, the first of which is increased temperatures which will lead to dryer soils, as water evaporates more quickly at higher temperatures, increasing severity of droughts. A warming atmosphere can also shift storm tracks, further exacerbating precipitation patterns. (Means, 2023) Although a correlation can be seen between drought frequency and global warming it does not always mean causation, as droughts are variable. "However, the more drought dovetails with trends of increasing temperature, decreasing precipitation, and with computer model projections, the more confident scientists are in pointing to climate change." (Means, 2023)

Drought manifests in various forms, each with distinct characteristics and impacts on different sectors. Meteorological Drought is a type of drought that occurs when a region experiences below-average precipitation over an extended period. It leads to diminished soil moisture and reduced water availability, affecting ecosystems, agriculture, and water resources management. Agricultural drought arises when soil moisture levels are insufficient to meet the needs of crops and other vegetation. Prolonged dry spells can severely impact crop yields, food production, and the agricultural economy, leading to economic losses and food insecurity. Hydrological drought results from deficits in surface water or groundwater availability in a particular region. It is characterized by low streamflow, depleted water levels in lakes and reservoirs, and compromised aquifers. Hydrological drought poses significant challenges for water supply, irrigation, hydropower generation, and ecosystem health. Socioeconomic drought refers to the impact of water shortages on human activities and socioeconomic systems. Water scarcity affects various sectors such as agriculture, industry, tourism, and municipal water supply, leading to economic losses, unemployment, food insecurity, and social unrest. Ecological drought occurs when there is insufficient water to support healthy ecosystems and biodiversity. It can lead to habitat degradation, reduced biodiversity, and ecosystem collapse, affecting wildlife and ecosystem services such as water purification, flood regulation, and soil stabilization. (Craig et al., 2019)

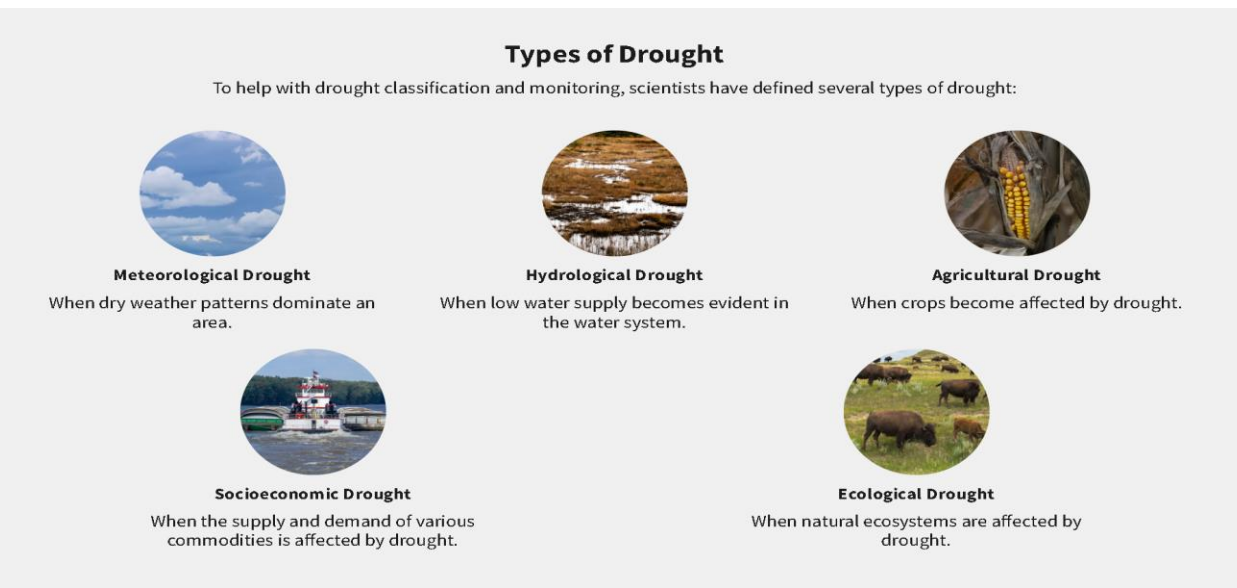

Figure 3: Short descriptions of each type of drought, provided by Drought.gov

Droughts pose significant threats to agriculture, impacting crop yields, food production, agricultural economy, and soil health. Insufficient soil moisture limits plant growth and development, affecting crop health, yield potential, pollination, and overall agricultural productivity. Dry weather conditions exacerbate soil erosion, nutrient depletion, and pest infestations, further compromising agricultural sustainability. Consequently, farmers face reduced incomes, increased financial burdens, and heightened food insecurity during prolonged drought periods.

Understanding the driving mechanisms of droughts is crucial for improving risk estimation and developing effective mitigation strategies. These mechanisms vary at different time scales. Short-term scales involve land-atmospheric interactions, local evapotranspiration, and moisture advection from surrounding regions, influencing precipitation patterns, and contributing to the development of seasonal droughts. Long-term scales are influenced by oceans, with oscillations in sea surface temperatures impacting meteorological drought frequency. Advanced statistical approaches, such as support vector machines (SVMs), are employed to capture the nonlinear relationships between meteorological droughts and their driving factors, enhancing prediction accuracy and informing management strategies. (Apurv et al., 2019)

In conclusion, droughts represent complex phenomena with multifaceted impacts on agriculture, water resources, economy, environment, and society. Integrating scientific research, social awareness, and technological innovations is imperative for effectively addressing the challenges posed by droughts and building resilience to future occurrences.

2.2 Drought in the Shenandoah Valley

Situated between the Blue Ridge Mountains and the Allegheny Mountains in Virginia, the Shenandoah Valley is within a temperate forest biome characterized by warm summers, cool winters, and significant rainfall. The valley's fertile soils and diverse plant and animal species thrive due to ample rainfall. However, despite its temperate climate, the Shenandoah Valley is not immune to drought conditions, especially during periods of prolonged precipitation deficits. (Singer, F., 2016) Furthermore, the valley's reliance on agriculture, particularly livestock and crop production, exacerbates the impact of drought, as water scarcity directly affects crop yields, soil moisture levels, and forage availability for livestock. Additionally, the valley's diverse ecosystem, including forests, wetlands, and rivers, faces disruptions due to prolonged drought conditions, leading to diminished biodiversity, increased wildfire risks, and habitat degradation.

In recent years, the Shenandoah Valley has experienced recurrent drought events, highlighting the urgency of addressing drought resilience and mitigation strategies. The increasing frequency and severity of droughts emphasizes the need for proactive measures to manage water resources effectively, enhance agricultural practices, and safeguard ecological integrity. Collaborative efforts among stakeholders, such as researchers, farmers, and local communities, are essential for developing comprehensive drought plans, implementing sustainable water management practices, and promoting resilience-building initiatives.

This is a major concern as the Shenandoah Valley is the highest agricultural productive part of the state of Virginia. The valley contains 4 out of 5 of the highest agricultural markets sales in Virginia, as seen in **Figure 4**. Rockingham County is by far the leader with 22% of total Agricultural Market Sales, this is followed by Augusta at 8%, and then Page and Shenandoah County at 4% each. These 4 counties account for 38% of the Toal Agricultural Market Sales in Virginia. The region is dominated by agriculture, mostly focused on poultry and livestock, but grows crops to support the animals.

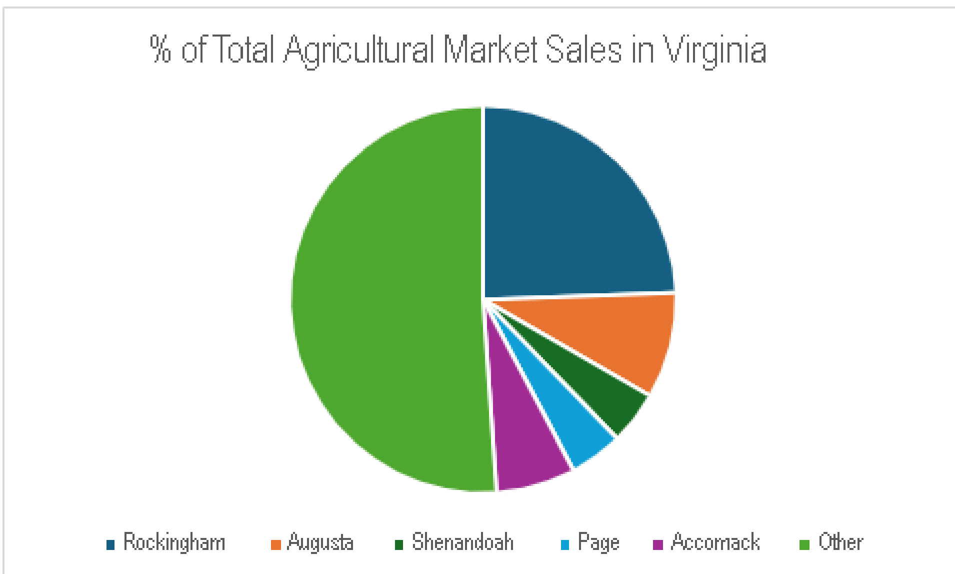

Figure 4: Pie Chart showing the % of Total Agricultural Market Sales in Virginia (2022)

2.3 Who is impacted by Drought?

Drought is a hazard that can affect populations at any place on the globe, and one of the world's costliest natural disasters, having major impacts of food security, health and population displacement, and migration. (*Drought*, 2020) The impacts of drought can be both direct and indirect within the agricultural sector.

Directly, drought manifests in dried crops, abandoned farmland, and withered pastures, representing significant losses for farmers and agricultural producers. Prolonged soil moisture deficits due to drought can lead to crop failures and pasture losses, resulting in economic hardships for farmers within the agricultural sector. Livestock producers face challenges in providing adequate forage and water for their animals, impacting livestock health and productivity. (Ding, Ya et al., 2011)

Indirectly, the impacts of drought extend beyond the agricultural sector, affecting the broader community and economy. Reduced agricultural production can lead to cascading impacts such as increased food prices, straining household budgets and affecting consumer purchasing power. Businesses that rely on agricultural inputs, such as food processing and distribution companies, may experience disruptions in their supply chains and increased operational costs. This can result in layoffs, reduced profitability, and economic uncertainty for employees and stakeholders. (Etumnu et al., 2023)

Furthermore, the environmental impacts of drought, such as environmental degradation and lower accessibility to water, can have long-term consequences for ecosystems and natural resources, such as biodiversity. (Orimoloye et al., 2022). Overall, the agricultural sector's vulnerability to drought in the Shenandoah Valley has far-reaching implications for both rural and urban communities, highlighting the interconnectedness of economic, social, and environmental systems.

Moreover, in regions like the Shenandoah Valley where drought is a recurring threat, water availability becomes a concern for residents, industry leaders, and governmental officials. The potential socio-economic hardships resulting from water scarcity underscore the importance of proactive drought preparedness and mitigation efforts at both the local and governmental levels.

2.4 Causal Loop Diagram

Below is a causal loop diagram to give a general overview of many of the key stakeholders, highlighted in red, and how they are affected by an agricultural drought. Looking over Figure 1 it is a lot to break down, to begin Agricultural Drought is a center piece of the diagram. 2 Variables that effect and can define an agricultural drought, depicted by the arrows flowing into a variable, are temperature and precipitation patterns. This is due to elevated temperatures and deficient precipitation are main drivers of drought, and here is climate change effecting these both as well. Therefore, this part of our diagram depicts climate change, increasing temperature and changing precipitation patterns leading to drought. Drought then will have many holistic impacts throughout the environment, the economy, as well as federal and local governments and society, including everyday consumers, businesses, farmers, and other vulnerable populations. The final part of the diagram is drought management and mitigation strategies that can be used to lessen the effects of an agricultural drought.

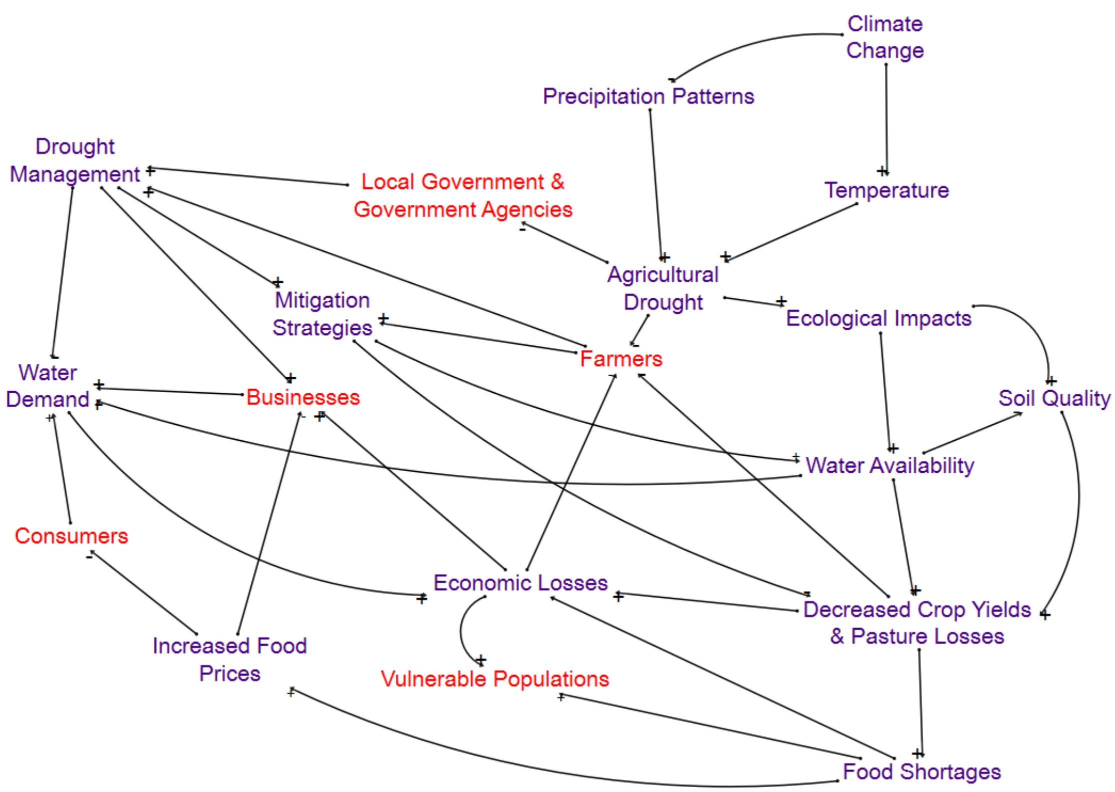

Figure 5: Casual Loop Diagram of Important Stakeholders and Effects of Drought

2.5 Interaction of Drought, Agriculture, and Stakeholders

An agricultural drought is a complex and multi-faceted hazard with impacts across many scales, affecting many different stakeholders, including farmers, governments, businesses, local consumers, and vulnerable populations. A drought can have cascading impacts, “in which one impact is connected to another, forming a chain reaction of impacts” (Cavalcante et al., 2024). The drought can have direct impacts derived from insufficient rainfall, resulting in low soil moisture, leading to reduced crop development, which yields reduced harvests. This has many environmental, but also socioeconomic effects. The farmer has diminished earnings during this period, contributing to high food prices due to shortages, culminating in heightened food insecurity. (Cavalcante et al., 2024)

The cascade of impacts can flow through and cause many following effects, the leading driver of the cascade of impacts is the absence of rainfall, kickstarting the process through direct impacts, such as localized water scarcity, crop development impacts, and increased risk of wildfires. This low water availability can have socioeconomic and agricultural consequences such as water trucks for farms and households. The lack of rainfall can lead to soil moisture deficiency, adversely affecting the cultivation of crops intended to feed livestock, forcing farmers to purchase animal feed. Adding on to this the reduced soil moisture can prompt drawing water from reservoirs, potentially diminishing their level (resulting in reduced streamflow and groundwater) which then can lead to insufficient water available for irrigation and consumption. All these impacts are linked with the livelihoods and well-being of farmers, households, businesses, and government. (Cavalcante et al., 2024)

While drought can cause cascading impacts in agricultural and the economy there is also another concept know as cascading hazards, “events that occur in a specific order, where one event or hazard is typically caused or triggered by one or more preceding events or hazards” (AghaKouchak et al., 2023) Drought can lead to various hazards, including heatwaves, wildfires, debris flows, floods, and water quality. All of these can also playoff off each other and cascade onto the next hazard.

Government has a huge role to play in this as many of their policies are responsible to intervene to alleviate the ongoing drought impacts cascade. There are many examples of those, one of which is cistern to hold water in case of drought, along with water trucks to distribute water. There are also socioeconomic policies, such as crop insurance, that will provide relief and finance for farmers and families struggling with crop losses. (Cavalcante et al., 2024) Along with this many areas and cities implement water conservation measures to lower the commercial and individual amount of water used, depending on the stage of drought as well. (“Upper Shenandoah River Basin, Drought Preparedness and Response Plan,” 2011)

2.6 Current Mitigation Strategies

Addressing drought is of paramount importance due to its wide-ranging impacts on ecosystems, agriculture, water resources, economies, and human well-being. In regions heavily dependent on agriculture, such as the Shenandoah Valley, drought can have profound socio-economic ramifications, including decreased agricultural productivity, increased food prices, and rural unemployment, increasing poverty and inequality. Addressing the complex interplay between climate change and drought requires integrated approaches that combine mitigation efforts to reduce greenhouse gas emissions with adaptation measures to enhance resilience in affected regions.

Prioritizing drought management practices, sustainable land, and water practices, along with agricultural mitigation strategies, such as irrigation coverage, drought-tolerant crop varieties and high-yielding variety seeds, are vastly important for preparing and lessening the impacts of drought (Eludoyin et al., 2017). Government also has a huge role in this, although many government policies are reactive, and they help alleviate the impact post-drought or during drought, such as relief programs or crop insurance. These are crucial for slowing the cascading impacts of drought, but more proactive measures can help enhance resilience in the community and promote sustainable practices among the agricultural sectors.

There are also many drought indices that depict various levels of severity of drought, each useful the drought exposure of a state. The main one that is planned to be used for this report is the U.S. Drought Monitor, which contains full weekly reports from 2000-present and shows the recent frequency of drought in the area. The U.S. Drought Monitor uses 5 categories (D0-D4) ranging from D0 (Abnormally Dry) to D1 (Moderate Drought) to D4 (Exceptional Drought). These categories each have an assorted color associated with it and are useful to map to depict the drought frequency in an area.

Pre-disaster mitigation strategies also play a huge role in preparation for mitigating droughts' future effects. This aim to improve the level of readiness and capabilities for responding to drought, this would include “water supply augmentation and conservation, expansion of irrigation facilities, effective dealings with drought, and public awareness and education” (Eludoyin et al., 2017) These practices would help a community better prepare to face drought and could be of use in the Shenandoah Valley. There are also proactive options to mitigate the impacts when drought does occur, including “the development of an early warning system and crop insurances.” (Eludoyin et al., 2017)

2.7 The Benefits of Addressing Drought

Droughts are one the costliest natural hazards there are, and they can have wide and sweeping consequences across multitudes of space and time. Therefore, addressing drought in regions like the Shenandoah Valley offers numerous benefits, particularly in safeguarding agricultural productivity and enhancing community resilience. By analyzing the potential severity of drought and its interactions with agriculture in the region, farmers and rural communities can formulate better mitigation efforts, leading to reduced economic losses during drought periods. Such initiatives empower farmers with actionable information, enabling them to make informed decisions about crop management, water conservation, and resource allocation. Local government can also better prepare for drought and take proactive measures in the community to implement water conservation policies and relief efforts.

The impacts of drought extend beyond the agricultural sector, affecting various facets of the community and economy. Businesses reliant on agricultural inputs may face disruptions in their supply chains, resulting in operational challenges and economic uncertainties. Addressing drought through proactive measures not only mitigates these economic consequences but also fosters greater social cohesion and stability within the community.

Climate change has exacerbated the frequency, duration, and severity of droughts, making proactive measures even more critical. By recognizing the influence of climate drivers such as temperature dynamics, precipitation patterns, and atmospheric circulation, stakeholders can better anticipate and prepare for drought events. Seasonal forecasts and climate projections enable informed decision-making, facilitating timely interventions to minimize the impacts of drought on agriculture, water resources, and the broader environment. Overall, addressing drought in the Shenandoah Valley and similar regions not only protects agricultural livelihoods but also promotes sustainable development and resilience in the face of climate variability.

2.8 Drought in the Future

Drought in the Shenandoah Valley is a pressing concern that is expected to worsen in the coming years due to the compounded effects of climate change, population growth, and increasing water demand. However, climate change is altering these patterns, leading to more frequent and severe droughts across the state and in the

Shenandoah Valley. Rising temperatures contribute to increased evaporation rates, intensifying water scarcity during dry periods.

One of the primary drivers of worsening drought conditions in the Shenandoah Valley is climate change. According to climate projections, the region is expected to experience higher temperatures and changes in precipitation patterns, with more frequent and intense droughts becoming increasingly common (Chapter 22: Southeast, 2023). These changes not only impact water availability but also exacerbate other environmental challenges, such as ecosystem degradation and habitat loss. In addition, the agricultural sector, a significant contributor to the region's economy, faces substantial risks from prolonged droughts, including crop failures, reduced yields, and increased irrigation demands.

In addition to environmental and demographic factors, socio-economic considerations also play a significant role in shaping the impacts of drought in the Shenandoah Valley. Efforts from farmers to better prepare mitigation strategies if drought does occur and Government help will be crucial in the case of severe droughts and a united and resilient community will be better prepared to face the impacts of drought.

3. Materials and Methods

3.1 Introduction

In this project, we analyzed drought data and created an interactive dashboard for displaying climate data and drought conditions. Additionally, we will conduct a stakeholder analysis and incorporate insights gathered from interviews with key stakeholders. The project was divided into several key phases, each requiring specific skills and culminating in intermediate and final deliverables.

3.2 Required Resources (Skills, Knowledge, Materials)

The first phase of the project involves collecting historical drought data from reliable sources such as government agencies, meteorological organizations, and research institutions. This data will include variables such as precipitation levels, and minimum and maximum temperatures. The collected data will then undergo preprocessing, including cleaning, filtering outliers, and standardizing formats to ensure consistency and accuracy. During this phase, the team will collaborate to identify and gather relevant datasets, conduct data quality assessments, and develop scripts or tools for data preprocessing. Skills required for this phase include data collection and management, programming (e.g., Python, R), data preprocessing techniques, and domain knowledge in climate data and environmental science.

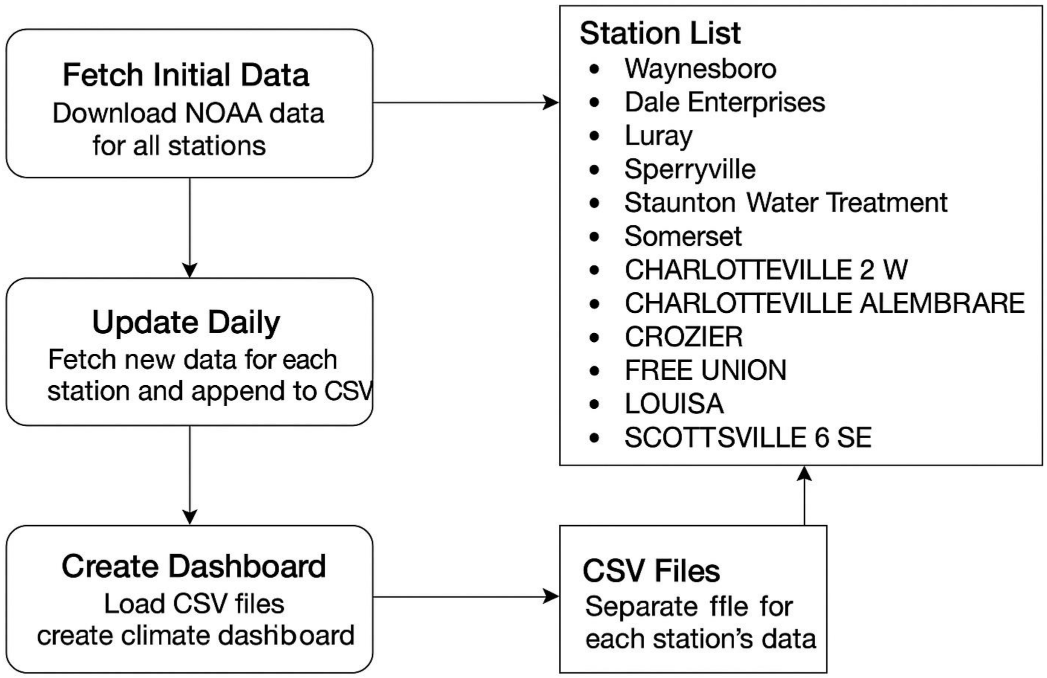

Figure 6: Python Workflow Diagram

We will perform comprehensive data analysis to identify drought patterns, trends, and severity levels. This analysis may involve statistical methods, machine learning algorithms, and geospatial techniques for mapping and visualization. Concurrently, we will develop an interactive dashboard using suitable tools like Power BI, or Plotly. The dashboard will mirror what the dashboard created by Drought.gov in a smaller region with data provide users with real-time or near-real-time insights into drought conditions, enabling them to explore data, view trends, and make informed decisions. We will analyze drought data, apply statistical and machine learning models as needed, design the dashboard interface, and integrate interactive features for data exploration. Skills required include data analysis, statistical modeling, machine learning, geospatial analysis, dashboard development, and user interface design.

In addition to the analysis and development of the interactive dashboard, we will conduct a stakeholder analysis to identify relevant stakeholders such as professors, agriculture experts, water resource managers, and extension agents. We did formal IRB Training and were certified to do our study, our number being IRB-FY25-246. The researcher worked with colleagues and JMU professors to examine drought conditions and potential stakeholders. Open-ended, semi-structured interviews were conducted via snowball sampling in the Shenandoah Valley, Virginia. Interviews were conducted over the phone, in person, or over zoom. The data collection began with a preparation phase to finalize interview questions and recruit research subjects. Qualitative data were gathered from interviews, and the analysis phase followed using thematic analysis, among other data analysis methods. This data encompassed insights into agricultural and societal impacts of drought, mitigation strategies, agricultural productivity, data sources, government assistance, climate change, and future concerns and preparedness. Skills required for this phase included stakeholder analysis, qualitative research methods, interview techniques, communication skills, and empathy for understanding user perspectives.

In the final phase, we will integrate insights from the stakeholder analysis and interviews into the dashboard design. This may involve refining dashboard features, adding customized functionalities based on user feedback, and optimizing the dashboard for accessibility and usability. The final dashboard will undergo testing and validation to ensure its accuracy, reliability, and effectiveness in communicating drought-related information to stakeholders. The team will integrate stakeholder insights into the dashboard, conduct usability testing, gather feedback from stakeholders, make iterative improvements, and finalize the dashboard for deployment. Skills required for this phase include dashboard refinement, user experience design, usability testing, iterative development, and project management.

4. Results

4.1 Stakeholder Analysis

Drought in the Shenandoah Valley has a profound and multidimensional impact on both the agricultural economy and the daily decisions of farmers. The immediate effects on crops and livestock quickly cascade into broader economic and ecological disruptions. Farmers throughout the region describe their operations as being in a delicate balance, one that drought easily disrupts.

Livestock producers face acute challenges. As pastures dry out, the availability of forage declines rapidly, forcing farmers to purchase supplemental feed, often at elevated prices. With water sources running low and wells becoming unreliable, some producers were forced to reduce herd sizes. This response, while necessary in the short term, undermines long-term profitability. As a Virginia Cooperative Extension agent observed, “Virginia is land rich but cash poor.” Many producers have the acreage to support larger herds, but in drought years, the carrying capacity of that land shrinks dramatically, and with it, the potential income.

The crop sector experiences similarly disruptive effects. Corn, a staple forage and cash crop in the Valley, is particularly sensitive to heat stress. A farmer in Rockingham County recounted losing nearly half of their corn yield after a prolonged period of temperatures above 90°F killed the pollen: “Once that happens, there’s nothing left to save—it’s just dry stalks.” Tomatoes, soybeans, and hay yields also declined significantly during drought periods, and planting cover crops became less viable due to lack of soil moisture. These crop failures have cascading effects—not just on the individual farm, but across supply chains that depend on consistent local production.

In response, farmers across the region have adopted a variety of mitigation strategies aimed at reducing vulnerability. Crop mitigation efforts include shifting toward drought-tolerant varieties and experimenting with warm-season grasses like switchgrass and Bermuda grass that can withstand higher temperatures and limited rainfall. Others invest in cover crops, which help retain soil moisture and reduce erosion during dry spells. However, not all producers can afford the upfront costs, and implementation remains uneven.

Drought preparation remains mostly informal and reactive, but some farmers are adopting Best Management Practices (BMPs) promoted by Virginia Cooperative Extension and the Virginia Department of Agriculture and Consumer Services. These include rotational grazing, strategic hay storage, and soil health improvements through organic amendments and minimal tillage. While these practices are gaining traction, adoption is often limited by labor shortages, cash flow constraints, or skepticism about long-term benefits.

Both short- and long-term strategies are supported by access to government support. USDA drought assistance programs have been a critical lifeline for many producers. These include cost-share programs for water infrastructure, emergency feed assistance, and financial aid for herd reductions. Farmers also rely on crop insurance to mitigate losses, though some noted that payouts do not always reflect actual on-farm impacts. Moreover, the application process is often described as burdensome or confusing, especially for small-scale or beginning farmers.

Data still plays a role, though more as a complement than a centerpiece in most decision-making. The U.S. Drought Monitor, NOAA weather stations, and USDA resources like the Census of Agriculture are commonly referenced to understand regional trends. Localized insights from Virginia Cooperative Extension are considered particularly useful, as they offer tailored guidance and technical assistance. However, farmers emphasized that the most valuable information still comes from “walking the land”—observing pasture conditions, monitoring livestock behavior, and drawing from years of experience.

Climate change surfaced repeatedly as a long-term concern, though not always by name. Most farmers acknowledged that growing conditions are shifting and that extreme weather events—including drought—are becoming more frequent and intense. Despite this awareness, discussions about climate policy or systemic mitigation efforts were limited. Farmers framed their response in terms of stewardship: protecting the productivity of their land and passing it on to the next generation.

While government regulation did not dominate the conversation, it was occasionally mentioned in the context of conservation requirements and financial incentives tied to USDA and state programs. Most farmers welcomed technical support but expressed concern that overly rigid mandates could hamper flexibility in the face of unpredictable conditions.

In summary, the impacts of drought in the Shenandoah Valley are deeply felt across agricultural sectors, with livestock and crop losses leading to economic strain and a growing demand for adaptive practices. Mitigation efforts are underway, but barriers related to cost, access to support, and long-term planning remain.

4.2 Interactive Dashboard

The result of this project is a fully functional and interactive drought monitoring dashboard tailored to the Shenandoah Valley. Built using Dash by Plotly, the application visualizes daily NOAA climate data—including maximum and minimum temperatures and cumulative precipitation—for twelve weather stations in the region.

The dashboard allows users to select a station and a year, dynamically updating three key graphs to compare that year's conditions against long-term historical averages. Shaded regions display ±1 standard deviation from the mean, highlighting temperature and precipitation anomalies that could indicate drought.

Additional visual elements include a bar chart showing land use practice levels by county, an indicator graph displaying the average land use index for the valley, and a map of station locations generated with Folium.

To support accurate analysis, two backend Python scripts were developed: one to download the full historical dataset from NOAA, and another to append new records daily, ensuring the data remains up to date.

The dashboard is deployed on Render, a cloud-based hosting platform, and configured to run as a live web service accessible at any time. It connects data, analysis, and policy-relevant insights through an intuitive, user-friendly interface.

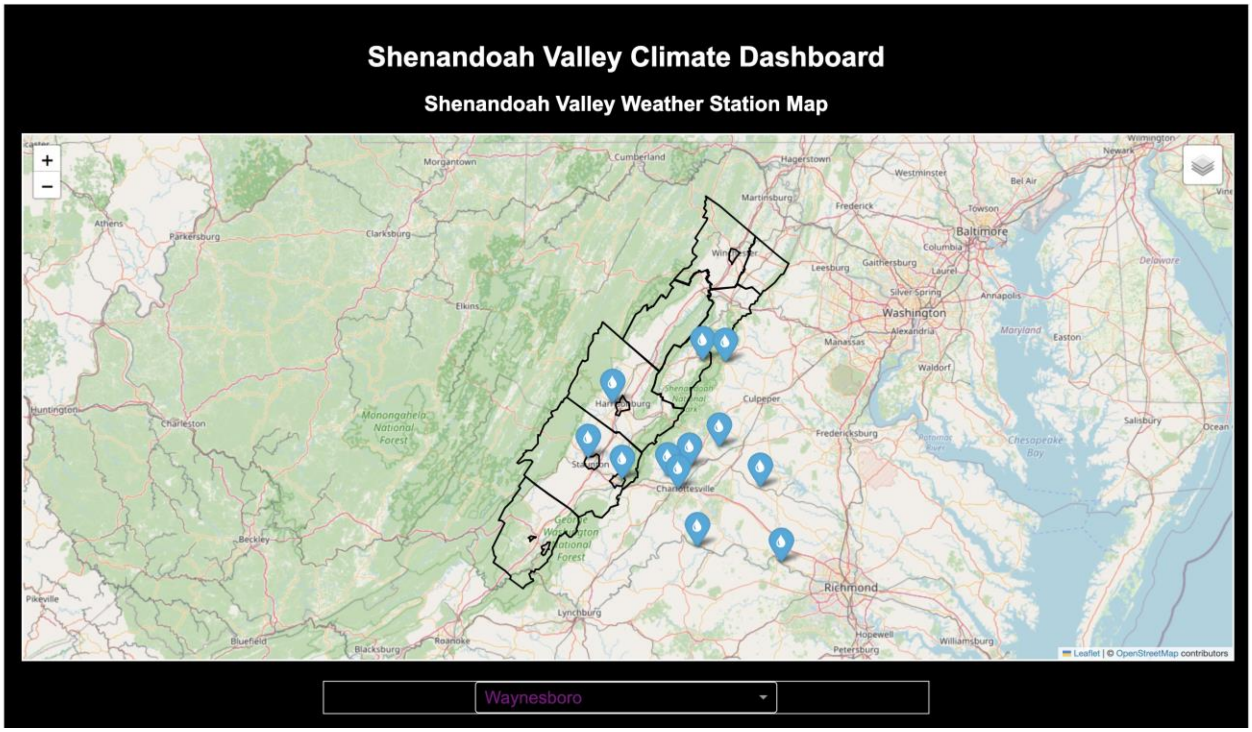

Figure 3: Final Dashboard Application

5.0 Discussion

Drought in the Shenandoah Valley is more than a periodic disruption—it is an intensifying stressor that exposes long-standing vulnerabilities in the region's agricultural systems. As producers navigate increasingly variable conditions, they often do so reactively, constrained by tight margins, limited water infrastructure, and the immediate demands of livestock and crop survival. While some mitigation strategies are emerging, adaptation remains uneven and shaped by access to capital, support services, and local knowledge.

To complement this understanding of on-the-ground experiences, a climate data dashboard was developed to help visualize local drought risk over time. By translating NOAA and USDA datasets into accessible, interactive tools, the dashboard aims to support more education awareness and support system for agricultural producers and the broader community. Together, the findings and the tool highlight both the complexity of drought impacts and the value of regionally tailored data in strengthening resilience.

5.1 Stakeholder Analysis

Drought in the Shenandoah Valley is not simply an environmental challenge—it is an intensifying socio-economic stressor that exposes long-standing vulnerabilities in the region's agricultural systems. As this analysis demonstrates, the effects ripple across sectors, particularly impacting livestock and crop producers, and revealing a fragile balance between land capacity, economic viability, and adaptive resilience.

A recurring theme among farmers and extension agents is the reactive nature of decision-making. The Valley's producers often lack the resources or lead time to plan proactively for drought; instead, they respond in real-time, focused on short-term survival. This reflects a broader pattern in agriculture where decisions are shaped less by long-range planning and more by the immediate demands of weather, markets, and available support. The observation by a Cooperative Extension agent that "Virginia is land rich but cash poor" underscores this tension—many producers have the land base to be more resilient, but without adequate infrastructure, financial reserves, or access to timely support, that land cannot fulfill its productive potential during drought.

This aligns with broader climate data indicating that Virginia's growing zones are migrating northward, altering traditional planting schedules and increasing crop stress. Yet, while scientific literature frames these changes in terms of climate adaptation and risk management, producers more often describe them through the lens of stewardship—caring for the land and sustaining it for future generations. This language of responsibility, rather than regulation, points to a cultural framework that must be respected and integrated into policy and extension strategies.

Mitigation efforts are taking root, but they remain uneven. Producers experimenting with drought-tolerant crops, warm-season grasses, and soil health practices are often those with better access to capital or institutional support. Meanwhile, others are constrained by thin margins, labor shortages, or uncertainty about returns. As your findings show, practices like cover cropping or rotational grazing are promising but require upfront investment and often long-term vision—something hard to prioritize when drought forces immediate decisions like buying expensive feed or selling livestock.

Government support plays a vital role, particularly through USDA assistance programs and crop insurance, but accessibility and effectiveness vary. Many farmers, especially small or beginning ones, find application processes cumbersome

While data use emerged in the results, it serves more as a backdrop than a decision driver. Farmers trust their own observations and experience more than satellite tools or regional forecasts. Extension services remain a critical bridge here, helping translate broad-scale data into locally relevant advice. But the gap between state- or federal-scale information and on-the-ground needs remains a barrier to proactive drought planning.

The stakeholder analysis drove the development of the dashboard by revealing a clear need for tools that translate broad climate data into locally meaningful, actionable insights. Farmers and extension agents emphasized their reliance on personal observation and experience, noting a lack of accessible resources to support proactive drought planning. In response, the dashboard was designed around localized NOAA data, simple visualizations, and real-time updates—not only to aid decision-making, but to lower barriers to understanding and using climate information effectively.

More than just a data platform, the dashboard also serves as an educational tool. It reflects the values and language of stewardship voiced by producers, offering resources that connect climate trends to conservation practices and adaptation strategies. By grounding technical information in the realities of Valley agriculture, the dashboard supports both immediate planning and long-term learning, empowering users to build resilience while staying rooted in their land and community.

Ultimately, drought in the Valley highlights the need for both structural support and cultural alignment. The resilience of the region's agriculture will depend not only on access to better water management tools, insurance, and adaptive technologies, but also on policies that acknowledge the values and lived experience of farmers. Stewardship, not compliance, is the foundation on which most farmers build their response to drought. Future strategies must support that ethic while lowering the barriers to proactive planning, enabling the Valley's agricultural community to weather a more uncertain future.

5.2 Interactive Dashboard

The development of this dashboard demonstrates how open-access climate data can be transformed into a decision-support tool for addressing regional drought risk. By visualizing localized temperature and precipitation data across the Shenandoah Valley, the dashboard helps users identify abnormal seasonal patterns and evaluate climate variability over time.

The architecture of the dashboard is intentionally modular. Climate data is downloaded via NOAA's API, processed into station-specific CSVs, and updated daily through automation scripts. These files are then read into the visualization layer, where Dash and Plotly present the information interactively. A custom Folium-generated map shows where stations are located, and additional dashboard elements connect land use practices to broader climate resilience planning.

Deploying the application through Render ensures that the tool is publicly available and can scale with future updates. Whether accessed by farmers, researchers, or policy planners, the dashboard bridges the gap between raw climate data and actionable insight, contributing meaningfully to the region's drought preparedness efforts.

5.3 Next Steps

To build upon the current functionality of the dashboard and further enhance its value to stakeholders in the Shenandoah Valley, several key next steps are proposed:

1. **Automated Real-Time Data Integration**
   Transition from CSV-based updates to direct real-time data retrieval using NOAA's API. This would reduce maintenance and ensure the dashboard reflects the most current weather conditions without manual intervention.

2. **Incorporation of Drought Indices**
   Future versions of the dashboard may integrate standard drought metrics such as the Palmer Drought Severity Index (PDSI) or the Standardized Precipitation Index (SPI) to provide a more comprehensive assessment of drought severity, as well as incorporating and updating the U.S. Drought Monitor.
3. **Expanded Interactivity and Comparative Features**
   Adding the ability to compare multiple years simultaneously or view multi-station trends would enable deeper temporal and spatial analysis of drought patterns across the region.
4. **User Testing and Feedback Collection**
   Conducting usability testing with local farmers, conservation professionals, and policy stakeholders would provide valuable feedback to guide iterative improvements in layout, accessibility, and functionality.
5. **Mobile Optimization**
   Enhancing the dashboard's responsiveness for mobile and tablet devices would increase its utility for users in the field, particularly those involved in agriculture and resource management.
6. **Geographic Expansion**
   The platform could be scaled to include additional information such as land use / land cover, precipitation levels based on county, or agricultural productivity.
7. **Educational Resource Integration**
   Adding curated resources—such as USDA conservation program information, climate adaptation strategies, and funding opportunities—would extend the dashboard’s role as an educational and planning tool.

6.0 Conclusion

In conclusion, this project offers a comprehensive examination of the multifaceted impacts of drought in the Shenandoah Valley, particularly in terms of agriculture, the economy, and society at large. The stakeholder analysis provided valuable insights into the nuanced ways in which drought affects agricultural productivity, soil health, and economic stability, while also uncovering the existing mitigation strategies and support systems currently in place. These insights helped to shape the development of the information dashboard, which serves as a key tool for local farmers and community members, providing a clear, visual representation of drought severity and its impacts on agriculture in the region.

Through stakeholder interviews with farmers, extension agents, and agricultural experts, it became clear that producers are highly attuned to the realities of drought—but are often forced into reactive responses due to limited resources, infrastructure, and financial flexibility. Many are aware of and attempting mitigation strategies such as rotational grazing, warm-season forage, and improved water management, but adoption is uneven, often constrained by labor shortages or capital costs. The cultural framing of stewardship, rather than regulation, also emerged as a key lens through which farmers view both the land and potential policy interventions.

The development of an interactive dashboard addressed a critical need for localized, accessible climate data. By visualizing precipitation and temperature anomalies across the region using NOAA datasets, the dashboard enables farmers and community members to track abnormal seasonal patterns and better understand long-term climate variability. This tool enhances decision-making and awareness at the farm level and serves as a foundation for future planning and drought preparedness.

By integrating scientific data with community knowledge, the dashboard is designed not only as a decision-support tool but also as an educational resource that empowers stakeholders to take proactive steps in preparing for and mitigating drought effects. The tool supports more informed, localized decision-making, helping to enhance both short-term resilience and long-term drought preparedness. Ultimately, this project combines technical innovation with the practical needs of the Shenandoah Valley, offering a solution that addresses the pressing challenges of drought while strengthening the region's agricultural and economic stability.

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