A Survey of Drought Impacts and Mitigation Planning in Kentucky

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A SURVEY OF DROUGHT IMPACTS AND MITIGATION PLANNING IN KENTUCKY

A Thesis
Presented to
The Faculty of the Department of Geography and Geology
Western Kentucky University
Bowling Green, Kentucky

In Partial Fulfillment
Of the Requirements for the Degree
Master of Science

By
Crystal Jane Bergman

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A SURVEY OF DROUGHT IMPACTS AND MITIGATION PLANNING IN KENTUCKY

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Drought is a well-known and costly climate-related natural hazard. Unlike other climate-related natural hazards, droughts are usually long in duration and may cover a large region, the physical boundaries of areas affected by drought are sometimes arbitrary, and the impacts are sometimes difficult to identify. Climate records since 1895 show that drought has occurred periodically in Kentucky. The drought of 2007 was the most recent drought to affect Kentucky and is the primary focus of this research. The purpose of this research is to identify impacts of drought and potential vulnerabilities to various drought impact sectors in Kentucky so that policymakers can develop a drought plan that addresses these vulnerabilities and emphasizes mitigation efforts.

An historical analysis of drought was provided for the following droughts that occurred in Kentucky: 1930-31, 1940-42, 1952-55, 1987-88, and 1999-2001. A more in-depth analysis of the development and impacts of the drought of 2007 was conducted. Weekly drought reports from the drought of 2007 that were published by the Kentucky Division of Water were used for analysis. The reports discussed streamflows, PDSI values, precipitation deficits, lake levels reports from the U.S. Army Corps of Engineers, and other information that documented the progress of the drought. Impacts caused by the drought of 2007 were identified mostly through news reports.
Agriculture and water supplies were determined to be most impacted by drought; therefore, two separate surveys (one regarding drought impacts on agriculture in 2007, the other regarding drought impacts on water supplies in 2007) were created to increase the understanding of how the drought of 2007 affected agriculture and water supplies in Kentucky. Other impacts from the drought of 2007 that were studied include impacts on recreation and tourism, the number of fires and wildland fires, plant and animal species, and small businesses.

It was found that droughts that have affected Kentucky have originated in all directions and have spread northward, southward, eastward, and westward into Kentucky. The temporal scale of these droughts has also varied. Impacts caused by the drought of 2007 in Kentucky were very similar to impacts caused by historical droughts. However, the documentation of drought impacts that occur in Kentucky needs improvement. Agricultural impacts are documented better than any other impact, while impacts on water supplies, recreation and tourism, the occurrence of wildland fires, plant and animal species, and small businesses are not as well documented. It is recommended that conducting an extensive analysis of how various sectors are vulnerable to drought in Kentucky and educating the public on the importance of drought awareness should be addressed by policymakers involved in the development of Kentucky’s state drought plan.
CHAPTER 1

INTRODUCTION

Climate-related natural hazards occur throughout the world and adversely affect people and the environments in which they live. Hazards occur at various spatial and temporal scales. Global hazards, such as climate change, disrupt weather patterns and global circulations and may cause changes in global precipitation and temperature. Implications of climate change may include impacts on water resources, agriculture, forests, biological diversity, and human health (Smith and Tirpak 1990; Cowie 2007; IPCC 2007). Climate change may also bring about changes in atmospheric patterns, such as an increase in the occurrence and severity of hurricanes, the intensification of mid-latitude storms, and an increase in the frequency of floods and droughts (Burroughs 1997; Cowie 2007; IPCC 2007). These changes could disrupt human life and place a tremendous amount of stress on people.

People often place themselves at risk and are vulnerable to hazards for a number of reasons. Many people make their homes near coastlines that are frequently impacted by tropical systems. Others do not educate themselves concerning the hazards that their regions are prone to and therefore do not understand the consequences of living there. Planning for hazards and educating people about the risks hazards pose to them are necessary measures that should be taken by policymakers. Unfortunately, most plans are reactive instead of proactive to hazards, meaning they do not implement measures to mitigate impacts caused from hazards. Hazard mitigation is the key to minimizing loss of life and property (Knutson et al. 1998; Abraham 2006).
Drought is a well-known climate-related natural hazard and is reported as the most costly (Keyantash and Dracup 2002; Svoboda et al. 2002). According to the National Drought Mitigation Center (NDMC), drought can generally be defined as a deficiency of precipitation over an extended period of time that results in a water shortage (2006a). A universal definition of drought has not been agreed upon, making it difficult for policymakers to develop drought plans and allocate funds to drought-stricken areas (Wilhite and Glantz 1985; Redmond 2002). Unlike tornadoes or tropical systems, the beginning and end of droughts are sometimes hard to determine. Also unlike other climate-related natural hazards, droughts are usually long in duration and may cover a large region. The physical boundaries of areas affected by drought are also sometimes vague.

The impacts of drought are also difficult to identify. The location of a drought and the location of its subsequent impacts are often disconnected. The region that has received the least amount of rainfall may not be the same region where the impacts are occurring. Some impacts occur that are directly attributable to drought, while other impacts are indirectly caused by drought. Direct impacts, such as water shortages, are usually not difficult to identify. Indirect impacts, such as increased revenues caused by increases in water usage, are challenging to identify as impacts are further removed from the underlying causes. Complex economic linkages also make it difficult to calculate economic loss if the impacts are not direct.

All of the aforementioned issues cause people to not consider drought as a serious threat. Compared to other natural hazards, drought impacts may not be immediately evident. Often there is a lag between the onset of the drought and its resulting impacts.
Drought may also soon be forgotten after a precipitation event. Figure 1 is a depiction of the “Hydro-Illogical Cycle,” an animated representation of the ambiguous nature and resulting perception of drought. The longevity and ambiguity of drought present challenges for policymakers during preparation of a drought mitigation plan. It is also difficult to convince people that over time, drought is a serious threat to sectors such as agriculture and water supplies, and appropriate measures should be taken to protect them.

![Figure 1. The Hydro-Illogical Cycle. Source: NDMC 2007b.](image)

Climate records since 1895 show that drought has occurred periodically in Kentucky. Every drought that has occurred has been unique in its development and abatement, spatial and temporal extents, and degree of severity. Some impacts have disappeared over time, while other impacts have tended to recur. It is important that impacts are thoroughly documented because they reveal how drought affects human life, the environment, and the economy. Knowing how drought impacts these sectors would help policymakers devise a plan that prepares citizens for drought. A drought impact
analysis would also be very helpful to policymakers because the information could be used to allocate the appropriate funds for sectors most affected by drought.

The drought of 2007 was the most recent drought to affect Kentucky and is the primary focus of this research. Information and data needed to analyze the impacts of this drought were more accessible and readily available. Also, research regarding general drought impacts in Kentucky was ongoing when the drought of 2007 developed, so the focus of the research was shifted to completing a case study on this drought. The purpose of this research is to identify impacts of drought and potential vulnerabilities to various drought impact sectors in Kentucky so that policymakers can develop a drought plan that addresses these vulnerabilities and emphasizes mitigation efforts. Assessing a region’s vulnerability to drought is a necessary precursor to drought mitigation planning to ensure the appropriate mitigation strategies are implemented. This research is also intended to become a potential model for drought impact research in other states that are developing drought plans emphasizing mitigation. The research intends to reflect the objectives of the National Integrated Drought Information System (NIDIS), which will be discussed later in the text.

The following questions will be addressed: What are the drought impacts that affect Kentucky and which ones have the greatest consequences? How do the impacts caused by the drought of 2007 compare to impacts that have occurred during historic Kentucky droughts? How well are drought impacts documented in Kentucky? Will the implementation of Kentucky’s newly-created drought plan minimize the severity of drought impacts and prepare citizens for forthcoming droughts? Addressing these
questions will contribute to a greater understanding of how drought affects Kentucky so that Kentuckians can be better prepared for the next drought that occurs.
2.1 Definition of Drought

Research suggests that there cannot and should not be a universal definition of drought because the meaning of drought is multifaceted (Wilhite and Glantz 1985; Heim 2002; Redmond 2002; Boken et al. 2005). Instead, drought should have several definitions that each focus on a different aspect. Drought definitions are considered either conceptual or operational (NDMC 2006a). Conceptual definitions are generalized and are often used for the establishment of drought policies. For example, drought may be conceptually defined as “a protracted period of deficient precipitation resulting in extensive damage to crops, resulting in loss of yield” (NDMC 2006a). Operational definitions usually denote the temporal scale and severity of a drought, are more specific, and are unique for each drought.

Wilhite and Glantz (1985) identified four primary drought definitions: meteorological drought, agricultural drought, hydrologic drought, and socio-economic drought. A meteorological drought definition is dependent upon the degree of dryness and the lack of rainfall over a specified period of time. The definition usually differs from place to place because of the variety of climates. An agricultural drought definition is usually a combination of meteorological drought characteristics and agricultural impacts. For example, various meteorological factors, such as evapotranspiration, are taken into account in an agricultural drought definition. The onset of an agricultural drought often lags behind a meteorological drought.
A hydrologic drought definition focuses on changes in surface or subsurface hydrology, streamflow, and runoff. A hydrologic drought may not necessarily coincide with a meteorological drought or an agricultural drought. A socio-economic drought definition incorporates water supply and demand issues and addresses conflicts between water users. Socio-economic drought usually occurs after the other drought types as water supplies decrease and the demand for water increases. Each of the aforementioned definitions reflects some of the impacts caused by droughts and reveals the complex nature of drought development.

2.2 Drought Monitoring

A number of methods have been developed to monitor drought conditions. Drought indices incorporate data from a variety of indicators, such as rainfall and streamflow, to arrive at specific values that are placed on a scale for assessment. Some drought indices were developed to compare moisture content in various regions, but this is very difficult due to the lack of homogeneity of topography, soil, and climate across regions. Also, the difficulty of defining a drought presents the problem of the inability to devise a universal drought index (Heim 2002). Selected major drought indices that are used in the U.S. are described in Table 1. Although there were many drought indices introduced in the early 20th century, W.C. Palmer’s development and introduction of the Palmer Drought Severity Index (PDSI), the Palmer Hydrological Drought Index (PHDI), and the Z Index (collectively known as the Palmer Index) in 1965 was revolutionary (Heim 2002).
<table>
<thead>
<tr>
<th>Name of Index</th>
<th>Origin</th>
<th>Overview</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent of Normal</td>
<td>N/A</td>
<td>Simple calculation used by TV weathercasters and general public</td>
<td>Useful for comparing single regions or seasons</td>
<td>“Normal” depends on long-term averages and may not correspond to expected outcomes</td>
</tr>
<tr>
<td>Palmer Drought Severity Index (PDSI)</td>
<td>Developed by W.C. Palmer in 1965</td>
<td>Soil moisture algorithm based on homogeneous regions</td>
<td>First comprehensive drought index developed in the U.S.</td>
<td>Not as useful for heterogeneous regions; not effective as an early drought detection tool</td>
</tr>
<tr>
<td>Crop Moisture Index (CMI)</td>
<td>Developed by W.C. Palmer in 1968</td>
<td>A PDSI derivative used to assess moisture supply in the short term across major crop-producing regions</td>
<td>Identifies potential agricultural droughts</td>
<td>Not designed to assess long-term droughts</td>
</tr>
<tr>
<td>Surface Water Supply Index (SWSI)</td>
<td>Developed by Shafer and Dezman in 1982</td>
<td>Designed to complement PDSI for use in Colorado; based on snowpack, streamflow, precipitation, and reservoir storage</td>
<td>Represents water supply unique to each river basin</td>
<td>New algorithms must be calculated if there are any changes in data collection or water management; too specific to compare river basins</td>
</tr>
<tr>
<td>Standardized Precipitation Index (SPI)</td>
<td>Developed at Colorado State University in 1993</td>
<td>Based on the probability of precipitation for any time scale</td>
<td>Less complex than PDSI; effective as an early drought detection tool</td>
<td>Values based on preliminary data may change</td>
</tr>
<tr>
<td>Reclamation Drought Index (RDI)</td>
<td>Developed by the Bureau of Reclamation in Oklahoma</td>
<td>Similar to SWSI except that it incorporates temperature</td>
<td>Temperature component accounts for evaporation</td>
<td>Too specific to compare river basins</td>
</tr>
</tbody>
</table>

Table 1. Major Drought Indices Used in the United States. Data Source: NDMC 2006c.
Prior to the development of the Palmer Index, drought indices were developed using simplistic methods and were typically based on a rainfall deficiency (Heim 2002). The Palmer Index was unique because it was the first comprehensive drought index developed in the U.S. (Heim 2002; NDMC 2006c). Palmer recognized that there is a lag between the meteorological conditions that end a drought and the time the environment takes to recover from a drought so he developed the PDSI to measure the former and the PHDI to measure the latter. Short-term wet and dry spells were determined using Palmer’s moisture anomaly index (item 4 in Palmer’s procedures listed on page 12) which has come to be known as the Palmer Z index. Palmer’s objective was to standardize measurements so that comparisons could be made between locations and months (NDMC 2006c).

The original study was based on western Kansas and central Iowa because they are climatically dissimilar (Palmer 1965). Palmer wanted to compute an index that included more than precipitation, so he compiled data using the variables of the water balance equation (precipitation, runoff, evapotranspiration, and change in storage). Soil moisture storage was based on two layers: a surface layer and an underlying layer. He assumed that the surface layer contained one inch of available moisture at field capacity, and that rain falls and evaporation takes place on this layer. He also assumed that moisture could not be removed from the underlying layer of soil until all moisture had been depleted in the surface layer. Likewise, he assumed that recharge could not occur in the underlying layer until the surface layer had been replenished to field capacity. Palmer also stated that evapotranspiration losses occurred if potential evapotranspiration exceeded precipitation during a given month.
Palmer (1965) developed the following five procedures to compute the index:

1) Carry out a hydrologic accounting by months for a long series of years.
2) Summarize the results to obtain certain constants or coefficients which are dependent on the climate of the area being analyzed.
3) Reanalyze the series using the derived coefficients to determine the amount of moisture required for “normal” weather during each month.
4) Convert the departures to indices of moisture anomaly.
5) Analyze the index series to develop criteria for determining the beginning and ending of drought periods, as well as a formula for determining drought severity.

Palmer classifications typically range from -4.00 to 4.00 (although values can fall outside of this range) with an increasing positive value denoting increasingly wet conditions and a decreasing negative value denoting increasingly dry conditions (Palmer 1965). PDSI values indicate the probability that a wet or dry spell has either started or ended. Figure 2 is an example of a PDSI map. The Climate Prediction Center (CPC) publishes weekly PDSI maps by climate division and weekly PDSI percentiles by climate division and state on their website.

The Palmer Index does have some limitations, however. A majority of critics have concerns over Palmer’s use of water balance models in general, and/or Palmer’s model in particular (Heim 2002). The following are more specific examples of issues that have been raised over Palmer’s methods:
1) Selected values that signal the beginning and end of a drought are based solely on data from western Kansas and central Iowa and have little scientific meaning (NDMC 2006c).

2) The Palmer Index only takes into account local precipitation as the primary source of moisture and does not account for other moisture sources such as snowmelt, frozen ground, or irrigation (Alley 1984).

3) Variables such as soil type are too generalized to be applied to an area as large as a climate division. Furthermore, the model assumes no annual or seasonal fluctuations in vegetation cover or root development (Alley 1984).

4) Potential evapotranspiration calculations that are based on the work of Thornthwaite were used by Palmer and are widely accepted, but they are only approximations (NDMC 2006c).

5) The Palmer Index is not effective as an early drought detection tool because it does not account for the lag between precipitation and the resulting runoff, so Palmer values may lag emerging droughts by as much as several months (Alley 1984).
Multiple drought indices have been developed since the Palmer Index (Table 1), but none have been proven to be superior to it (Heim 2002). Some drought indices have been developed to address issues with the Palmer Index, while others have utilized new methods of measuring drought. The Standardized Precipitation Index (SPI) was developed in 1993 as an alternative to the Palmer Index for Colorado (Heim 2002). SPI is less complex than the Palmer Index because it is only based on the probability of precipitation for a particular time scale (NDMC 2006c). SPI intends to assess wet or dry periods on various time scales while providing information on precipitation deficit, percent of average, and probability (McKee et al. 1993). SPI requires only one input variable that can be any of the following usable water sources: soil moisture, groundwater, snowpack, streamflow, or reservoir storage.

SPI is calculated by fitting a long-term monthly precipitation dataset to the Gamma distribution and then transformed into a normal distribution so that SPI has a mean of zero (McKee et al. 1993). The Gamma distribution is commonly used for representing precipitation data because it is bound on the left by zero and positively skewed, therefore eliminating the issue of having negative precipitation values (Wilks 2006). SPI is uniquely related to probability, can be used to calculate the precipitation deficit and current percent of average precipitation for a given period of time, and is normally distributed so that both wet and dry periods can be assessed (McKee et al. 1993).

Similar to the Palmer Index, wet and dry spells are assessed on a scale where positive values indicate wet spells and negative values indicate dry spells. A drought begins when an SPI value first becomes negative for a given location and time period,
and a drought ends when an SPI value becomes positive after having an SPI value of -1.00 or less (McKee et al. 1993). Drought categories are assigned to the ranges of SPI values. Figure 3 is an example of 3-month SPI and accompanying legend of values and categories.

![3-month SPI through the end of May 2009](image)


SPI exemplifies versatility because short- and long-term wet and dry periods can be identified (Heim 2002). For example, a study of short-term droughts may be necessary for agricultural purposes, while long-term drought assessments would be more appropriate for hydrological purposes. It also serves as an early drought detection tool, which is something the Palmer Index cannot do. The only major limitation of SPI is that values based on preliminary data may change (NDMC 2006c).

Some indices have been developed to accommodate more specific needs, such as the Crop Specific Drought Index (CSDI), which assesses wet or dry conditions for specific crops (Hubbard 1993). The Surface Water Supply Index (SWSI) is another example of a drought index developed for a specific region. In the case of Colorado, SWSI’s computation relies heavily on snowpack and is calculated for each river basin.
SWSI would not be practical to use in regions that do not rely on snowpack as a water source. Drought indices are commonly examined together because none of them can accurately assess drought conditions for every region (Wilhite et al. 2005).

The U.S. Drought Monitor, a product of the NDMC, is an important method used to monitor drought and is comprehensive for the entire country (Boken et al. 2005; Schubert et al. 2007). It was developed in 1999 following costly droughts in the mid to late 1990s through the collaborative efforts between the NDMC, the National Oceanic and Atmospheric Administration (NOAA), and the United States Department of Agriculture (USDA). In 2001, the National Climatic Data Center (NCDC) joined the partnership (Svoboda et al. 2002). The primary goal of developing the Drought Monitor was to improve drought monitoring in the U.S. The Drought Monitor is distributed weekly by utilizing various drought indices and input from climate and water experts. Figure 4 is an example of the Drought Monitor. Its classification consists of one category that denotes abnormal dryness (D0), and four categories that describe the severity of drought (D1 = Moderate Drought, D2 = Severe Drought, D3 = Extreme Drought, D4 = Exceptional Drought). It also conveys regions experiencing agricultural impacts (letter A) and hydrological impacts (letter H). The Drought Monitor quickly became popular with the media, agricultural producers, and a variety of other groups, and most users have acclaimed its simplicity and straightforward design (Svoboda et al. 2002). However, the Drought Monitor is intended to serve as a generalized drought monitoring tool and is not able to capture drought severity at the local level. The success of the Drought Monitor caught the attention of drought experts in Canada and Mexico, ultimately leading to
collaboration among these countries and the U.S. to develop the North America Drought Monitor (Lawrimore et al. 2002).

Regional drought monitoring can be greatly enhanced by the development of automated, meso-scale weather data networks, also known as mesonets. The Oklahoma Mesonet has laid the ground work for future mesonets and serves as an example to climatologists in other states on how to develop and maintain the network. Funded by the State of Oklahoma, it was developed through a joint partnership between the University of Oklahoma and Oklahoma State University (Brock et al. 1995). It consists of more than 110 surface observing stations strategically placed across the state that transmit data in real time every five minutes to various agencies, including both government and private organizations (McPherson et al. 2007). These stations measure a range of meteorological variables, such as air temperature, humidity, barometric pressure, wind speed and direction, rainfall, solar radiation, and soil temperatures. Other mesonets have

been developed across the country, including the Texas Mesonet, the Iowa Environmental Mesonet, and the Kentucky Mesonet, which will be discussed later. A dense network of high-quality climate monitoring stations across the country would provide very useful climate data that would aid in early drought detection, giving stakeholders ample time to prepare for forthcoming droughts.

Some states are developing their own unique methods to monitor drought that are more specific and better suited for their states. An historical analysis of drought in Arizona was conducted that standardized PDSI and SPI by creating a frequency distribution of index and percentile values by water-year (Goodrich and Ellis 2006). This method can be used by policymakers to assess and monitor drought conditions by comparing the current drought conditions to past conditions. In South Carolina, research has been done that integrates various tools and methods in a Geographic Information System (GIS) with drought detection variables and indices to produce advanced tools for drought monitoring and early detection (Carbone et al. 2008; Rhee et al. 2008). Early detection of droughts is a monumental achievement because it greatly enriches drought planning strategies. These methods that have been developed for specific states serve as examples to other states that may be interested in developing their own drought monitoring tools.

2.3 Drought Impacts and Vulnerability

Although drought is an extremely costly climate-related natural hazard, very little has been done to analyze the impacts of drought for different regions (Abraham 2006; Schubert et al. 2007). Drought often creates a complex set of convoluted impacts that can be either direct or indirect. Reduced crop yield is an example of a direct impact of
drought. Increased produce prices at the supermarket that was caused by the reduced crop yield would be an indirect impact of drought. The further an impact is removed from the primary cause, the more difficult it is to trace it back to the cause, which makes it very difficult to arrive at an accurate cost of financial loss directly attributable to a drought (NDMC 2006d).

Drought impacts are classified into three major categories: economic impacts, environmental impacts, and social impacts (NDMC 2006d). Economic impacts may include agricultural losses, loss of revenue for recreation and tourism, loss of revenue for small businesses, and a range of other impacts. Environmental impacts may include disruption of area hydrology, damage to plant and animal species, and increased number and severity of wildfires. Social impacts may include health issues, increased conflicts among water users, and public dissatisfaction with government drought response. It is important to understand that some drought impacts can fall under multiple impact categories, or they may cause further impacts to occur. It should also be noted that not all drought impacts are considered negative. For example, higher water demand may lead to increased revenues for water utility companies and would be considered a positive impact for those companies.

A drought impact assessment may help determine areas of drought vulnerability, as well as subsequent vulnerability reduction strategies; however, very few state drought plans have vulnerability analyses incorporated into them (Abraham 2006). Factors to consider when identifying drought vulnerability are variation of precipitation, water supply-and-demand balance, water use patterns, and preparedness (Wilhite et al. 2005). The NDMC (2006e) has identified three steps that should be followed to determine a
region’s drought vulnerability: 1) identification of drought impacts and trends over time, 2) ranking of significant drought impacts, and 3) investigation of underlying causes of drought impacts.

When identifying drought impacts, it may be helpful to make a list and categorize them into economic, environmental, and social impacts. It may also help to look for patterns or trends that have occurred with historical droughts. Perhaps one of the best places to look for evidence of drought impacts is in news articles. The media frequently report drought impacts that are of greatest concern to the general public. Another source for drought impacts is the Drought Impact Reporter, found on the NDMC’s website, which houses and archives current and historical drought impact information (NDMC 2006e). In order to ensure that drought impacts are properly documented, there needs to be a network of observers that includes various state agencies and stakeholders who communicate their observations of impacts on a regular basis, especially during drought episodes.

After drought impacts are identified, they should be ranked to determine which impacts have the greatest effect and should be addressed first. A number of factors should be considered to help rank drought impacts appropriately, such as cost, trends over time, and public opinion (NDMC 2006f). The following questions should be addressed: What is the economic cost of this impact relative to others? What effect does this impact have on people in the drought-affected area? Is this impact a growing problem that must be addressed? What is the public opinion of this impact? These are just a few examples of questions that can be asked to help policymakers determine the impacts that are of greatest concern.
Finally, it is important to determine the underlying causes of drought impacts so that the actual problem is being addressed, not just one of the indirect impacts. This can be done by conducting a drought vulnerability analysis. Each high-priority drought impact should be examined by asking the following question: Why did this impact occur? There may be multiple answers to this question, and they should all be addressed. It may be useful to draw a tree diagram to display all possible reasons for the occurrence of the impact (Figure 5). Note that the bold items in Figure 5 are the actual underlying causes of the drought impact. These underlying causes are items that should be addressed by policymakers when creating their drought plans.

![Figure 5. Example of an agricultural impact tree diagram. Source: NDMC 2006g.](image)

Understanding the timing of the occurrence of drought impacts is very complex because impacts often do not occur simultaneously with the drought. For example, most plants tend to be fairly resilient to dry conditions, as long as they receive rainfall at some point during their reproductive cycles (Gonzales 2009a). Severe drought may occur during part of the growing season but if adequate rainfall occurs at some point during a plant’s reproductive cycle, it may not be greatly impacted by the drought. However, if
drought persists throughout the entire reproductive cycle of the plant, then it is going to produce low yields and will have been greatly impacted by the drought. These types of lags between drought conditions and impacts are also evident in other sectors and should be accounted for when planning for drought.

2.4 Drought Planning

Until recently, the drought planning initiative has been placed upon state governments (Abraham 2006). While a majority of states have implemented drought plans, the type of plan implemented varies from state to state (Figure 6). Most states have drought plans that emphasize response (also called crisis management), meaning the plan focuses on addressing drought-related issues during and after a drought. There are several states that have implemented plans emphasizing mitigation (also called risk management) that are more focused on taking preventive measures to minimize impacts before a drought occurs. Two states, Illinois and Washington, are developing long-term plans and are considering updating their plans (Hayes 2009). Two other states, California and Florida, do not plan for drought at the state level but have delegated drought planning to local authorities. There are also a few states that do not have drought plans. The following portion of the text examines drought plans from two selected states, Missouri and Illinois.

Missouri has a state drought plan that mostly emphasizes response. The plan was revised in 2002 by the Missouri Department of Natural Resources (MDNR 2002). A large part of the plan is an overview of Missouri’s susceptibility to drought. Annual precipitation, runoff, and lake evaporation were indicators used to determine susceptibility to drought across various regions in Missouri. The plan also includes four
phases of drought response: Phase 1 – Advisory Phase, Phase 2 – Drought Alert, Phase 3 – Conservation Phase, and Phase 4 – Drought Emergency. Each phase is determined by PDSI values, streamflow, reservoir levels, and groundwater levels. The plan has designated Impact Teams, composed of various agency staff members and technical experts, to monitor drought conditions as they develop and disseminate information to the Drought Assessment Committee. The plan alludes to a few mitigation strategies, such as post-drought evaluation procedures that assess the plan’s effectiveness after the occurrence of drought, but most of the plan focuses on the appropriate response measures that should be taken when drought is evident in Missouri.

Illinois’ state drought plan was drafted in 1983 and updates to this plan are being considered. Currently the plan emphasizes drought response, although there is a long-term planning component incorporated into the plan. The plan focuses on three primary areas: a drought response framework, public education, and weather modification (IDWR

Figure 6. Status of State Drought Planning. Source: NDMC 2006h.
The drought response framework involves the convention of the Drought Task Force, which is made up of various agency staff members with technical expertise in specific areas of drought management. The purpose of the Drought Task Force is to come up with solutions to minimize drought impacts. The plan also addresses the importance of public education, citing the specific role of the media in communicating the importance of water conservation practices to the general public. Weather modification is a suggested solution to alleviating drought, but the plan indicates that weather modification research is expensive and there are many scientific uncertainties regarding the outcome of these practices.

It is obvious after the review of two state drought plans that each state plan focuses on different aspects of drought management and is uniquely structured to meet the needs of that particular state. On the contrary, the majority of state drought plans share the purpose of minimizing the effects of drought impacts and/or developing procedures to mitigate future drought impacts. Kentucky’s drought plan was recently drafted and will be discussed later in the text.

Research suggests that existing state drought plans that take a reactive, crisis management approach should transition to more proactive drought plans that emphasize risk management (Wilhite 1993; Wilhelmi 1999; WGA 2004; Abraham 2006; NDMC 2006i). A 10-step process has been proposed to help policymakers develop drought mitigation plans (Wilhite et al. 2005). The steps are outlined in Figure 7, and an explanation of these steps will be provided in the following paragraphs. This process was designed to be used as a prototype for the development of drought plans at the national, state, or local level. Steps 1-4 are designed to gather the appropriate information and
people that are essential to the drought planning process. Step 1 is to appoint a drought task force. Appointed by a key governing official, the drought task force would be the sole supervisor of the development of the drought plan. The drought task force would ultimately be responsible for implementing the plan and making policy recommendations to the key governing official when drought occurs.

![Diagram of the 10-Step Drought Planning Process](image)


Stating the purpose and objectives of the drought plan is step 2. When defining the purpose of the plan, one should consider items such as the scope of the plan, historical drought impacts, drought vulnerability, and financial resources that can be used for the plan. Identifying specific objectives that accommodate the plan’s purpose is also important. Examples of objectives include collecting and analyzing information pertaining to drought, establishing sound communication between levels of government, and identifying drought-prone areas across the region for which the drought plan is being developed.
Step 3 requires the establishment of stakeholder participation. Stakeholders may have interests in agriculture, water supplies, public health, and various other sectors that are often affected by drought. It is important to include them in the drought planning process because they can contribute invaluable information from their respective areas of expertise. Also, collaboration with stakeholders may lead to more effective and innovative solutions to managing drought.

Creating an inventory of resources and conducting a risk analysis make up step 4. It is imperative that all natural, biological, and human resources are counted to determine the vulnerability of these resources to drought. Resources that are determined to be highly vulnerable to drought would likely need more attention than resources that are more resilient to drought. An inventory of resources can contribute to the delineation of areas that are at highest risk when drought occurs.

Step 5, which entails establishing and writing the drought plan, is the most complex, but most important, step to the drought planning process. As mentioned previously, steps 1-4 prepare policymakers to write the drought plan. There are three major components to step 5: 1) monitoring, early warning, and prediction; 2) risk and impact assessment; and 3) mitigation and response. Figure 8 is an example of a drought task force organizational structure that is suggested to aid in the drought plan development process. The drought task force is responsible for providing policy direction to the monitoring committee and risk assessment committee. The monitoring committee should consist of climatologists, meteorologists, and/or hydrologists that continuously monitor the climate and water supplies. The monitoring committee should provide situation reports to both the drought task force and the risk assessment
committee. The risk assessment committee should consist of representatives from various economic sectors, social groups, and ecosystems that are at highest risk from drought. These representatives should be divided into working groups according to their interests and expertise to evaluate possible impacts of and vulnerability to drought. The risk assessment committee should provide assessment reports to both the monitoring committee and the drought task force.


The third component of step 5, mitigation and response, is typically the responsibility of the drought task force, although a separate committee can be assembled to undertake this task. This committee would be responsible for collecting information from the monitoring and risk assessment committees to identify mitigation and response actions that are most appropriate for the region of interest. After the three components of step 5 are fulfilled, the drought plan can finally be written.
Steps 6 and 7 express the need for continued relationships between scientists and policymakers. Step 6 is to identify research needs and fill institutional gaps, meaning that research needs to be continued and gaps in the research should be filled to ensure that the drought plan is as complete and efficient as possible. Step 7 is to integrate the science and policy of drought management. This is important because a scientist’s knowledge about policy is often limited, and that also usually holds true for policymakers trying to understand science.

The significance of steps 8 and 9 are to promote and test the plan before drought occurs. Step 8 is to publicize the drought plan in order to build public awareness and consensus. The general public should be aware of and involved in drought planning from its early stages so that they fully understand the significance of the drought plan. Also, people who are informed about the drought plan are more likely to adhere to its principles. Step 9 aims to encourage the development of education programs to increase awareness of drought and its impacts. The drought plan can be promoted through the observance of Earth Day, the establishment of a drought awareness week, and/or the facilitation of workshops.

The final step, step 10, is to evaluate and revise the drought plan. Drought impacts and vulnerability may change over time, which would bring about the need for restructuring portions of the drought plan. Additionally, the occurrence of drought may cause the realization of new impacts that were not considered in the original plan. Routine maintenance of the drought plan would ensure its effectiveness as a tool to use when coping with drought and its impacts.
Drought planning has recently expanded to the national level with the launching of NIDIS and the U.S. Drought Portal (available at http://www.drought.gov). The national drought planning initiative began in 1996 when the Western Governors’ Association (WGA) pioneered the establishment of a national drought policy through the National Drought Policy Commission (NDPC). The NDPC recommended “improving collaboration among scientists and managers to enhance the effectiveness of observation networks, monitoring, prediction, information delivery, and applied research and to foster public understanding of and preparedness for drought” (WGA 2004). The 2004 report titled Creating a Drought Early Warning System for the 21st Century: The National Integrated Drought Information System represented the partnership between the WGA and NOAA that was established in 2003. The NIDIS Act was introduced to the U.S. Congress and signed by the President in 2006 (U.S. Drought Portal 2007).

The U.S. Drought Portal houses various drought products that are convenient for viewing and available to the general public, such as the U.S. Drought Monitor, streamflow data from the U.S. Geological Survey, the U.S. Seasonal Drought Outlook, the Drought Impact Reporter, and drought planning information from the NDMC. The U.S. Drought Portal also provides information regarding drought education and ongoing drought research. In addition to launching the U.S. Drought Portal, NIDIS is implementing various plans through Fiscal Year 2013 to further its interests in providing support to state governments for drought monitoring, response, and mitigation.
2.5 Drought Perception

Perception of drought widely varies among regions and groups of people. The problem of drought perception is closely linked to issues of defining drought. Aside from there being various types of droughts, there are also regional differences that exist that further complicate the issue of defining drought (Redmond 2002). For example, a person living in a region characterized by a generally wet climate is likely to have a different experience with drought than a person living in a region with an arid climate because climate expectations are drastically different for the two regions.

Another issue concerning drought perception is the differences in the interpretations of certain terminology and labels that are used to describe drought. Redmond uses the example of the Drought Monitor to illustrate this issue (2002). For instance, one person may consider severe drought to be worse than extreme drought, while another person may consider the opposite to be true. There is no standard terminology that is used that everyone interprets in the same manner. Likewise, it is nearly impossible to develop a standard terminology that everyone can agree upon.

In the same manner that people tend to interpret terminology differently, drought forecasts are also sometimes interpreted in different ways, or even misinterpreted. The accuracy and reliability of drought forecasts greatly determine the public’s perception of those forecasts (Changnon 2002; Changnon and Vonnahme 2003; Artikov et al. 2006; Hu et al. 2006). The CPC disseminates several drought forecast products that are made available to the general public. The U.S. Seasonal Drought Outlook is derived from probabilities guided by short- and long-range statistical and dynamical forecasts (CPC
Other products the CPC distributes that assess drought forecasts include the Climate Outlook, Streamflow Forecast, PDSI Forecast, and Soil Moisture Forecast.

A study was conducted throughout several midwestern states that were impacted by drought in 1999-2000 that discussed how agricultural producers and state and local water managers perceived drought forecasts distributed by NOAA, and the results were published in companion papers (Changnon 2002; Changnon and Vonnahme 2003). NOAA issued drought forecasts in March 2000 that indicated the intensification of the ongoing drought throughout the spring and summer across parts of the Midwest. However, unanticipated heavy rainfall occurred in late May and early June that ended the drought for most of the affected region.

Overall, agricultural producers in regions where the drought forecast was incorrect were most unhappy because the failed forecast caused many of them financial loss, with the loss of crop sales revenue being the most frequently reported issue (Changnon 2002). Water supply managers tended to not be as upset about the failed forecast because it did not really cause them any significant financial loss. In fact, none of the local water managers surveyed said they would no longer use climate forecasts because of the failed drought forecast. However, it was found in this study that some agricultural producers and water supply managers largely disregard drought forecasts, while some make minor changes to their planning decisions after viewing drought forecasts, and still others make major changes to their planning decisions because of drought forecasts. The degree to which drought forecasts are used in planning decisions depends on one’s level of knowledge or understanding of the drought forecasts and how the forecasts are used in one’s agency. The authors recommended that drought forecasts
should have the level of certainty incorporated into them for clarification purposes, and communication should be strengthened between NOAA and state climatologists because the state climatologists are the ones who usually interpret the forecasts for the agencies involved in drought planning.

In companion papers, Artikov et al. (2006) and Hu et al. (2006) demonstrated how farmers use climate forecasts and how those forecasts influence their planning decisions. The authors used the Theory of Planned Behavior, a concept that has been used to identify motivational factors that underlie decisions, to assess certain causal factors that are likely to affect forecast-use behavior. The three causal factors used in the study were attitude, social norms, and perceived control. Hu et al. (2006) found that farmer attitudes toward allowing forecasts to influence their decisions are that they generally do not greatly expect the forecasts to be that useful to them. Regarding social norms, the authors found that farmers tend to highly value the views of crop consultants and television/radio. The perceived control factor, or farmers’ perception of their own ability to use forecasts, was tested by having farmers list limiting factors that hinder their use of forecasts. Accuracy and reliability were at the top of the list.

Hu et al. (2006) found that 60-70% of farmers surveyed allowed weather information and forecasts to influence their planning decisions to some degree. However, their results suggest that some farmers misunderstand and/or misuse the forecasts. They concluded that farmers’ perceptions of weather and climate should be changed for their benefit. In order to accomplish this, weather information should be made easier to understand, more easily accessible, and more reliable. They recommended that farmers
should be educated on forecast value and usage, resulting in a group of informed citizens that would expand the demand for drought forecasts.
CHAPTER 3
METHODOLOGY

The methodology of this research encompasses a number of approaches. The historical analysis of drought in Kentucky includes the following drought episodes: 1930-31, 1940-42, 1952-55, 1987-88, and 1999-2001. The droughts of 1930-31, 1940-42, and 1952-55 were chosen for analysis because PDSI values suggest that these droughts were among the most historic to occur in Kentucky since climate record-keeping began, and documentation of impacts would most likely be easier to find. The droughts of 1987-88 and 1999-2001 were chosen for analysis because they were more recent droughts that affected Kentucky and their impacts could be compared to earlier historical droughts. Documentation of these droughts was found in archived climatological data kept by the Kentucky Climate Center (KCC) and a collection of newspaper articles and documents kept by the Kentucky Division of Water (KYDOW). A brief synopsis of the spatial and temporal aspects of each drought, as well as their corresponding impacts, was summarized for each of the droughts. A more in-depth analysis of the development and impacts of the drought of 2007 was conducted because it occurred while this research was being conducted.

The determination of each drought’s spatial and temporal aspects came through analyzing national maps of average monthly PDSI values for each climate division. The data were analyzed and the maps were created using ArcGIS® 9.3 software from the Environmental Systems Research Institute (ESRI®). A map template was created in ArcMap™, an ArcGIS® Desktop application, so that any annual dataset from 1895 to 2007 could be loaded and any month of data within that year could be viewed. A
symbology layer file (*.lyr) was created so that the same color scheme and range of values could be imported every time a new map was created. PDSI was used for the analysis because it is more widely used than other drought indices and a complete dataset of PDSI values since 1895 was available through the NCDC. The overall limitations of the PDSI that were described previously are recognized. Analysis of PDSI data at the climate division scale also presents an issue because of the localized nature of precipitation. Climate divisions are fairly large and do not always accurately represent the entire area. It is possible for one portion of a climate division to be much drier or wetter than another portion. Although maps of PDSI values highlight large-scale patterns of drought or excessive wetness, peak intensities of drought on smaller scales may not be accurately represented. Analysis at the climate division level should be performed with caution.

Documentation of impacts caused by earlier droughts was difficult to find. The U.S. Department of Commerce and the Weather Bureau (now called the National Weather Service) publish monthly climatological data for Kentucky that are compiled into annual reports. The data were formerly accompanied by commentary that provided monthly synopses of weather highlights. Impacts discussed from the droughts of 1930-31, 1940-42, and 1952-55 came from these reports. Reports of impacts that resulted from the droughts of 1987-88 and 1999-2001 came from the Kentucky Agricultural Statistics Annual Bulletins, KYDOW, and archives of news reports.

Monthly maps of PDSI values by climate division were also analyzed to determine the spatial and temporal extents of the drought of 2007. Additionally, weekly drought reports that were published by KYDOW were used for analysis. The reports
discussed streamflows, PDSI values, precipitation deficits, lake levels reports from the U.S. Army Corps of Engineers (USACE), and other information that documented the progress of the drought. Maps that interpolated precipitation departure from normal values were created using ArcGIS® 9.3 software. Departure from normal values were obtained from the NCDC for each cooperative observation station in Kentucky. Stations with missing data were not used to generate the maps, leaving a total of 27 stations that could be used for the analysis. The ordinary Kriging method, found in the Geostatistical Analyst extension of ArcMap™, was used for the spatial interpolation.

Impacts caused by the drought of 2007 were identified mostly through news reports. A sample of news articles was collected mostly from newspapers across the state. Some of these articles were collected by KYDOW, while others were collected through searches on the Internet. A total of 95 news articles were collected from 30 May – 30 September 2007. This time period was chosen because during these four months, the highest volume of news articles that discussed the ongoing drought was found. News stations from around the state also produced video clips concerning drought conditions and impacts, but they were very difficult to obtain due to copyright issues and were not included in this research.

News articles were archived and documented in a Microsoft Excel spreadsheet according to the following information: title of the news article, origin of the news article, date of publication, location the news article refers to, impacts reported, types of impacts, and key words. Using the NDMC’s impact classification system, each reported impact was classified under one of the following types of impacts: economic impact, environmental impact, or social impact. It is important to note that while some impacts
could arguably be classified under more than one drought impact type, all impacts in this case were classified under only one impact type. Key words were documented so that a person wanting to find a particular article within the spreadsheet could search for and easily find it. An analysis of the frequency of reported impacts helped to determine which drought impacts would be further analyzed in the study.

Agriculture and water supplies were determined to be most impacted by drought; therefore, two separate surveys (one regarding drought impacts on agriculture in 2007, the other regarding drought impacts on water supplies in 2007) were created to increase the understanding of how the drought of 2007 affected agriculture and water supplies in Kentucky. Texts by Gillham (2000) and Peterson (2000) were consulted for suggestions on survey preparation and analysis. Before the surveys could be conducted, the project had to be approved by the Human Subjects Review Board at Western Kentucky University (WKU). The surveys were web-based and were created using WKU’s Easy Survey Package software. A new e-mail account was created with a WKU domain name to use exclusively for the study. An e-mail was sent to each of the subjects that included the link to the appropriate survey. After the subjects completed and submitted the surveys, the results were sent to the principal investigator’s Easy Survey Program account.

Donald Dunn, County Executive Director for the USDA Farm Service Agency in Warren County, stated that county extension agents would most likely be able to provide the best answers to the survey questions (2008). Surveys were sent to every Cooperative Extension Service (CES) office in the state. Each county has one office, and there are 120 counties in Kentucky, so a total of 120 surveys were distributed. A small number of
surveys were returned, so data from the National Agricultural Statistics Service (NASS) and the Kentucky Agricultural Statistics and Annual Report bulletins were used to supplement the meager survey data.

The agriculture survey contained 17 questions. Questions 1, 2, and 3 were not analyzed because Question 1 required the respondent to agree to the terms of the survey before proceeding with the survey, Question 2 asked for the respondent’s name, and Question 3 asked the respondent to identify the county with which he/she was affiliated. Questions 4 – 17 were a mixture of open and closed questions, meaning that open questions allowed respondents flexibility in their responses, while closed questions did not. Responses to open questions were analyzed in terms of content by categorizing the responses, while responses to closed questions were displayed graphically for analysis.

The survey contained questions that asked the subjects to note crop and livestock impacts that were evident as a result of the drought, impacts that were unanticipated, and mitigation efforts. Refer to Appendix A for a copy of the agriculture survey questions.

Bill Caldwell of KYDOW suggested that water suppliers should be surveyed to determine drought impacts on water supplies. A number of steps were taken to determine which water suppliers in the state should be surveyed. A master list of water suppliers was obtained from KYDOW that contained information for 559 water suppliers. It was determined that a stratified random sample should be taken from this list according to the size of the population served by each of the water suppliers.

All water suppliers serving at least 20,000 people were surveyed because these 42 suppliers collectively serve over half the population in Kentucky. However, water suppliers serving fewer than 1,000 people were not surveyed because the smaller
suppliers would most likely bear little significance on this research. After analyzing the master list of water suppliers and determining where the equal breaks should occur, four classes were created to perform the stratified random sample. There were 74 companies serving 10,000-19,999 people, 81 companies serving 5,000-9,999 people, 68 companies serving 2,500-4,999 people, and 83 companies serving 1,000-2,499 people. In order to survey approximately the same number of people as those surveyed on agricultural drought impacts, it was determined that 25% of each of the classes should be surveyed. This meant that 19 water suppliers should be surveyed from the 10,000-19,999 class, 20 should be surveyed from the 5,000-9,999 class, 17 should be surveyed from the 2,500-4,999 class, and 21 should be surveyed from the 1,000-2,499 class. After adding the 42 waters suppliers serving at least 20,000 people, a total of 119 water suppliers were to be surveyed.

A stratified random sample was taken from each class using S-Plus® software. After arriving at the finalized list of water suppliers to be surveyed, e-mail addresses had to be obtained for each water supplier. This proved to be a true challenge because not every water supplier has an official e-mail address or even Internet service. A majority of the e-mail addresses were obtained from KYDOW, but there were several e-mail addresses missing. Phone calls were made to each of the water suppliers on the survey list that had not provided KYDOW with an e-mail address. Some of the e-mail addresses provided were personal e-mail addresses. Five water suppliers were unable to provide e-mail addresses, because either no one had an e-mail address to provide, or phone calls were not returned after multiple attempts. Additionally, 18 of the water suppliers never received the surveys because the e-mail containing the link to the survey was returned.
Some of the e-mail addresses did not exist, and some e-mail accounts were over quota. A total of 96 water suppliers actually received a survey by e-mail.

The water supply survey contained 24 questions. The first six questions requested general information from the respondents for identification purposes. The remaining portion of the survey asked respondents a range of questions that included identifying how the drought of 2007 affected water supplies, and what could be done to improve the current policies on mitigating drought. Some of the survey questions were submitted by Caldwell, and a couple of survey questions were offered by Dwight Williams of Bowling Green Municipal Utilities (Warren County). Refer to Appendix B for a copy of the water supply survey questions.

Other impacts from the drought of 2007 that were studied include impacts on recreation and tourism, the number of fires and wildland fires, plant and animal species, and small businesses. Data concerning impacts on recreation and tourism came from the Kentucky Department of Tourism, the USACE, personnel at Barren River Lake State Resort Park, and personnel from Bowling Green Parks and Recreation. Some data were obtained on agency websites, while other data were sent through electronic mail. Data on the number of wildland fires and the acreage burned were obtained from the Kentucky Division of Forestry. Several newspaper articles were also collected that discuss burn bans that were implemented across the state during the drought. Information concerning damage to plant and animal species came from newspaper articles and the Kentucky Department of Fish and Wildlife Resources. Finally, phone interviews were conducted to gather information on how the drought impacted a landscaping business and a car wash in Bowling Green. Information on impacts that was obtained from businesses in Bowling
Green is assumed to be representative of other similar businesses across the state that were affected by the drought.

A study was also conducted that assessed population change by drainage basin from 2000 to 2030 using GIS and will be discussed further in the conclusions. County-level population projection data for 2010, 2020, and 2030 were obtained from the Kentucky State Data Center in Louisville, while 2000 census block-level population data were obtained from the U.S. Census Bureau in the form of TIGER/Line® shapefiles. Six-digit Hydrologic Unit Codes (HUCs) were obtained from the Kentucky Geography Network. This level of aggregation of the HUCs was used because it represents the major drainage basins that are most recognized across the state.

Area was calculated for the 2000 census blocks, and then the blocks were clipped to the HUCs. The area of the newly clipped blocks was calculated, and then the new area was divided by the original area to create a ratio that determined how blocks were divided by the HUCs. The assumption was made that population was evenly distributed throughout the entire block. The ratio was then multiplied by the population of the block to get the population of the newly clipped blocks, hence the population of each of the HUCs. This calculation resulted in decimal numbers, and population must be in whole numbers, so the calculations had to be rounded. This resulted in a rounding error of 0.01%, or 402 people not being counted.

A different method was applied to the population projection data because data were only available at the county level. The total number of persons residing in each of the HUCs (calculated using 2000 census block data) was divided by the total number of persons living in all counties that were at least partially contained within a basin. This
calculation created a ratio that was applied to the projected data to get the projected population of each of the HUCs. The percentages of change from 2000-2010, 2010-2020, 2020-2030, and 2000-2030 were calculated to assess future positive and negative population growth in each of the major drainage basins.
CHAPTER 4

RESULTS

4.1 Historical Drought Analysis of Kentucky

Drought is not an uncommon occurrence in Kentucky. Since the official climate record for Kentucky began in 1895, episodes of drought have been recorded during nearly every decade. A look at PDSI values and annual precipitation deficits for each of Kentucky’s four climate divisions from 1895-2007 reveals intermittent periods of drought (Figure 9). Figure 10 is a spatial representation of Kentucky’s climate divisions. The severity of these droughts has varied both spatially and temporally; however, extremely low PDSI values suggest that the droughts that occurred in 1930-31, 1940-42, and 1952-55 were the most significant (Smith and Conner 1999; KCC 2007). The most recent droughts that have occurred in Kentucky took place in 1987-88, 1999-2001, and 2007. The aforementioned droughts, excluding the drought of 2007, will be discussed in the following text that will include synopses of PDSI values across the eastern half of the U.S. and evaluations of drought impacts where information is available. The drought of 2007 is the primary focus of this research and will be discussed later. For purposes of this research, wet and dry periods in the western U.S. were not considered for analysis.

4.1.1 Drought of 1930-31

The drought of 1930-31 is the worst drought ever recorded in Kentucky in terms of severity. The year 1930 began with drought appearing in the Northeast and Upper Midwest regions of the U.S., while excessive wetness existed across the Ohio Valley and southeast coastal regions. By February, abnormal wetness significantly diminished, and most of the eastern U.S. was dealing with drought, and by March, all four climate
divisions in Kentucky were experiencing dry conditions (Figure 11a). Below normal rainfall was recorded March-May 1930 for every state east of the Rocky Mountains except Nebraska and Florida (USDA 1931). Drought intensified rapidly across the eastern U.S. throughout the spring, summer, and fall, with the exception of southern Florida and parts of the Northeast (Figure 11b). According to PDSI values, the drought appeared to peak across Kentucky in December 1930 – February 1931 (Figure 11c). By April 1931, drought conditions appeared to be slightly alleviated across the Northeast, the Upper Midwest, and the Ohio Valley regions, but it appeared to intensify across the Southeast (Figure 11d). Finally, by December 1931, all climate divisions in Kentucky except the Eastern Climate Division were experiencing normal rainfall.

Figure 9. Historical PDSI and annual precipitation deviation values for (a) Western Climate Division, (b) Central Climate Division, (c) Bluegrass Climate Division, and (d) Eastern Climate Division. Source: KCC 2007.
An abnormal, late-April freeze caused the growing season to get off to a bad start. Corn and tobacco fared decently because of brief, heavy rainfall that occurred in May that helped temporarily relieve drought conditions (U.S. Department of Commerce 1930). However, July was particularly hot and dry as temperatures soared in some parts of Kentucky to record highs, including 114°F in Greensburg, and water shortages were becoming apparent across the state. Livestock were being fed with winter feed because pastures were nearly barren. In August and September 1930, only 27% and 26% of pastureland was in good condition, respectively (USDA 1931). The average percentage of good pastureland for that time of year was 83%. The water shortage caused farmers to sell livestock at approximately one-fifth their value, and livestock became sick from contaminated water.
Localized showers occurred throughout August 1930 that provided some relief for crops, but before long farmers had run out of corn stalks to use as feed and resumed selling livestock. More timely rains fell across Kentucky in September, especially in the northern part of the state, and many late crops fared much better. The growing season (April-September) only received about 51% of the average rainfall that normally occurs during this time period (U.S. Department of Commerce 1930). An early freeze around October 20 destroyed some of the late crops of potatoes and tomatoes, and water shortages were worsening. Many creeks and springs were dried up by late fall, and the drought continued to worsen throughout the winter months. Finally, precipitation returned to a more normal pattern by March 1931, alleviating drought for most of the
state, but dry periods occurred sporadically until the end of the year. Table 2 describes some of the agricultural impacts in more detail.

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<tr>
<th>Commodity</th>
<th>Impact</th>
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| **Corn**        | • Production down ~61% from 1929 to 1930  
|                 | • Average yield of 27.3 bushels per acre in 1929, average yield of 10.8 bushels per acre in 1930 |
| **Hay**         | • Production down ~51% from 1929 to 1930  
|                 | • Average yield of 1.42 tons per acre in 1929, average yield of 0.75 tons per acre in 1930 |
| **Cattle and Calves** | • Down 71,000 head on 1 January 1931 compared to 1 January 1930 |

Table 2. Crop Impacts Caused by the Drought 1930-31. Data Source: USDA 1930 and 1931.

Approximately one-third of public water supplies in Kentucky became so depleted that emergency measures had to be adopted (Tisdale 1931). Water hauling became common as communities sought out alternative water sources. Although the Ohio River still provided an ample supply of water for the duration of the drought, it experienced water quality issues as algal and plankton content rose well above normal levels. Water for drinking was coming from so many different sources that the State Health Department distributed anti-typhoid vaccines to nearly one million people.

The drought of 1930-31 was considered the worst drought on record when it occurred, and no drought has since matched its severity of impacts. Farmers were particularly hurt during this drought because it coincided with the Great Depression that brought a sharp decline in the demand for farm commodities worldwide (USDA 1931). Older citizens at the time the drought was occurring compared it to the drought of 1854-55, but thorough climate records were not kept until 1895, so very little data existed at
that time. However, data were kept in Danville, Millersburg, and Springdale, and during the summer of 1854, rainfall was below normal and temperatures were well above normal. Millersburg recorded only 0.03 inches of rain in September 1854 (KCC n.d.). Springdale recorded 21 days in July, 20 days in August, and 15 days in September with high temperatures above 90°F.

One mitigation action that was executed before the drought of 1930-31 occurred was the federal government’s completion of a project involving the construction of 50 dams along the Ohio River (Anon. 1930). The pools of water created from the dams prevented many communities from having emergency water shortages. If the dams had not been built before the drought occurred, the hydrological impacts would have undoubtedly been substantial.

4.1.2 Drought of 1940-42

In the fall of 1939, drought was ongoing across much of the U.S., especially across parts of the Midwest, and spread to Kentucky from the Midwest and the Northeast (Figure 12a). Although drought relief came in spring of 1940, the drought quickly re-intensified throughout the summer and fall (Figure 12b). Some cooperative observation stations recorded temperatures of at least 100°F in every month June to September (U.S. Department of Commerce 1940). The drought began to spread southward from the Ohio Valley region and reached peak intensity in Kentucky by May 1941 (Figure 12c). The station at Earlington, located in Hopkins County, recorded a temperature of 101°F during that month. Most stations recorded mean temperatures well above normal during April to October 1941. The drought persisted in Kentucky until early summer 1942 when
precipitation patterns returned to normal. By then, the Midwest had entered into an abnormally wet pattern (Figure 12d).

The drought of 1940-42 impacted agriculture and water supplies. Similar to the drought of 1930-31, a severe freeze in April 1940 severely damaged crops that were planted prior to the freeze, especially potatoes. Corn and tobacco also experienced stress from the drought. Total tobacco production in 1941 was down ~13% from 1940 (USDA 1941). The summers of 1940 and 1941 were particularly hot and dry, which caused water shortages throughout the duration of the drought. Localized rain showers fell during these summers and brought temporary relief to crops and water supplies, but excessively dry conditions shortly thereafter abated soil moisture and surface water,
leaving crops and water supplies as stressed as they were before the rain showers occurred.

4.1.3 Drought of 1952-55

The drought of 1952-55 was of especially long duration in Kentucky. The drought was ongoing across the southern U.S. during the first half of 1952, and by June, it had spread into all of Kentucky (Figure 13a). Most of Kentucky experienced well above normal mean temperatures in June and July, and all but two stations recorded a high temperature of the year of at least 100°F (U.S. Department of Commerce 1952). The drought continued to intensify through the summer and fall of 1952, eventually spreading into the Midwest (Figure 13b). Relief from the drought finally came to Kentucky in spring 1953 but again rapidly intensified and persisted through the summer and fall. In early September 1953, most stations recorded temperatures of at least 100°F (U.S. Department of Commerce 1953). The drought finally peaked in December 1953 and was centered upon the middle-Mississippi and Ohio Valley regions, while wet conditions had developed across the southeastern U.S. (Figure 13c). By summer and fall 1954, the drought had spread throughout the southeastern U.S. and the southern and central Plains (Figure 13d). The drought continued to persist in Kentucky until February 1955.

Agricultural impacts from the drought of 1952-55 appeared first in western Kentucky and eventually spread eastward to the rest of the state. Corn and hay received the most damage from the drought, and an emergency hay program was established to help farmers who had lost most of their hay crop. Pasture conditions were also very poor.
As of 1 September 1952, only 52% of pastureland was rated in good condition (compared to the average of 82%), and only 50% of the pastureland was good as of 1 September 1953 (compared to the average of 80%). Small grains and tobacco fared well for the most part during this drought. For more information on agricultural impacts, see Table 3. There was no mention in the commentary of drought impacts on water supplies, although it is probable that there were localized issues with water shortages.

Figure 13. PDSI values for (a) June 1952, (b) October 1952, (c) December 1953, and (d) July 1954. Data Source: National Climatic Data Center.


4.1.4 Drought of 1987-88

The year 1987 began with a moist spell across the Midwest, the Southeast, and the Eastern Seaboard, and drier conditions in the Ohio Valley and Great Lakes regions (Figure 14a). Throughout spring and summer 1987, drought conditions rapidly intensified and the drought shifted southward from the Great Lakes region into the southeastern U.S. (Figure 14b). May was exceptionally warm as many stations reported temperatures well above normal for the month. In general, temperatures were slightly above normal during the summer, peaking in August (U.S Department of Commerce 1987). The drought across Kentucky seemed to slightly diminish during winter 1988, but it rapidly re-intensified during summer 1988, reaching its peak in June (Figure 14c). Summer 1988 was also very warm and most stations recorded temperatures of at least 100°F in July, the highest temperature of 109°F being recorded at Nolin River Lake (U.S. Department of Commerce 1988). By fall, Kentucky and the southeastern U.S. began transitioning into a wetter pattern and the drought retreated to the upper Midwest (Figure 14d).

According to documentation from KYDOW, a range of impacts occurred with the drought, including impacts on agriculture, water supplies, communities, emergency

<table>
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<tr>
<th>Commodity</th>
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<tbody>
<tr>
<td>Corn</td>
<td>• Production in 1952 down ~28% from 1951</td>
</tr>
<tr>
<td>Tobacco</td>
<td>• Production in 1953 down ~11% from 1952</td>
</tr>
<tr>
<td>Hay</td>
<td>• Average yield in 1952 was 1.05 tons per acre, which was down from the 1941-50 average of 1.29 tons per acre</td>
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</table>

response, and public health (KYDOW n.d.). Table 4 is a summary of crop conditions in 1987 and 1988 for tobacco, corn, and soybeans. In comparison to 1987, grain stocks in 1988 were significantly lower, including decreases in corn by 16%, wheat by 24%, oats by 8%, barley by 68%, sorghum grain by 53%, and soybeans by 28%. Livestock were sold because they were losing weight and feed prices were high. Some farmers even sold part of their breed stocks, suggesting that they would incur long-term costs from the drought. Farmers also experienced increased production costs in both capital equipment and labor. Crop losses from 1988 were estimated at $400-$600 million in Kentucky.

Figure 14. PDSI values for (a) January 1987, (b) September 1987, (c) June 1988, and (d) October 1988. Data Source: National Climatic Data Center.
<table>
<thead>
<tr>
<th>Commodity</th>
<th>1987</th>
<th>1988</th>
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| Tobacco (Burley) | • Hot and dry summer caused farmers to cut tobacco earlier than normal to save the crop  
• Late-cut burley tobacco did not fare as well  
• Continued dry conditions into the fall delayed stripping, causing a reduced supply of burley tobacco | • Dry conditions in early summer caused burley tobacco to struggle in June, causing farmers who had water and financial means to irrigate  
• Timely rains in late July-early August revived tobacco crop  
• Harvest and stripping was later than usual, but burley tobacco crop was of better quality than 1987 |
| Tobacco (Dark) | • Type 22 Eastern Dark Fire Cured tobacco, Type 35 One Sucker Dark Air Cured tobacco, and Type 36 Green River Dark Air Cured tobacco all experienced record low harvested acreages and production up to that time period | • Type 22 Eastern Dark Fire Cured tobacco, Type 35 One Sucker Dark Air Cured tobacco, and Type 36 Green River Dark Air Cured tobacco all broke 1987’s newly set record lows for harvested acreage |
| Corn            | • Smallest crop since drought year of 1983  
• Corn planting slow  
• Quick harvesting because of the lack of soil moisture  
• Later corn plantings did not fare as well as earlier plantings | • Broke 1987’s newly set record low for smallest corn crop  
• Hot, dry summer caused corn crop to deteriorate  
• As it entered pollination stage in early July, majority of corn crop was rated in poor or very poor condition  
• Mid-July rains benefited only late-planted corn  
• Summer drought of 1988 caused more damage to corn than any other row crop |
| Soybeans        | • Smallest crop since 1972  
• Soybeans planted earlier than usual  
• Soybeans became stressed in August because of short moisture supplies and high temperatures | • Broke 1987’s newly set record low for smallest soybean crop  
• Late planting in extremely dry regions  
• Hot and dry August caused deteriorating soybean crop conditions |

In addition to crop losses, river flow problems occurred along the Mississippi, Missouri, and Ohio River systems (NOAA 1988). Across the southeastern U.S., including Kentucky, dry conditions in 1985-86 initially caused low flow problems in the three river systems. Although the systems temporarily recovered in late 1986-early 1987, the worsening drought conditions later in 1987 and in 1988 further exacerbated the low flow issues. Additionally, the Midwest experienced below-normal snowfall during winter 1988, causing much less snowmelt, which is a key input to the river flows. The level of the Mississippi River near Memphis was the lowest since record-keeping began in 1872. The primary impact caused by low river flows was the interruption of barge traffic. Low streamflows caused a buildup of sediment in some places that caused barges to get stuck. The U.S. Coast Guard closed the Ohio River north of Cairo, Illinois, for three days in June 1988 because over 700 barges were backed up near Mound City, Illinois. The barges were carrying approximately 200,000 bushels of grain worth more than $1 million at the time and the grain had to be stored on city streets in Mound City because of the closing of the river. Shippers and barge and tow owners experienced economic losses due to the low flow conditions, and an estimated 27.3 million metric tons of bulk commodities were lost.

The water shortages that occurred in Kentucky from the drought brought about the need for the revision of a water shortage response plan that was designed for local use (Caldwell 2009a). As of 18 October 1988, 49 Kentucky communities had been in some phase of the Local Water Shortage Response Program. The Local Water Shortage Response Program explains four phases of severity in the following order from least severe to most severe: Advisory phase, Alert phase, Emergency phase, and Water
Rationing phase (KYDOW 1988a). Ten of those 49 communities were in the Alert Phase at some point, and three communities were at some point in the Emergency Phase (KYDOW 1988a). Seven water systems had to augment their raw water source in response to water shortages.

According to a report compiled for the Water Management Task Force, aside from the rainfall deficit it is believed that the water shortages occurred because of a lack of preparedness (KYDOW 1988b). Reasons for not being prepared include the following: 1) many communities did not know they were vulnerable, 2) those communities that knew they were vulnerable did not have the financial means to do anything about it, and 3) a few communities did not manage water supplies very well during the drought. The report stated that the Local Water Shortage Response Program worked fairly well, but not as well as it should have because very few communities lowered their water usage to acceptable levels during drought conditions. The report further stated that to improve water shortage response, communities that are susceptible to raw water shortages should be identified, better data should be acquired, methods that eliminate shortage problems should be explored, and the water shortage response plan should continue to be improved.

KYDOW also conducted a survey to gather information from water utilities concerning water shortage issues during the drought of 1987-88. Survey results stated that 14% of the water utilities who responded to the survey experienced maximum day pumpage that exceeded plant capacity, which placed a great amount of stress on water systems. Ten of the water utilities surveyed stated they were going to make improvements to their infrastructure. In particular, Owensboro planned to spend $20
million on improvements, Paducah and Prestonsburg were each planning to spend $4 million, and Somerset planned to spend $2.5 million. As a direct impact from the drought, extra operating cost was mentioned by 19% of the survey respondents, which cost approximately $317,000.

Water conservation was requested by 64% of the water utilities that responded to the survey, but only 14% of them actually imposed legal restrictions on water usage, and 11% reported imposing mandatory restrictions on business and commercial use of water. One utility company reported imposing a surcharge for usage above an allowable amount. The State Department of Military Affairs participated in certain activities to help lessen the severity of drought impacts and incurred about $500,000 in personnel and equipment expenses. KYDOW spent an additional $76,320 in 1988 that was directly charged to shortage response activities. Public health was also impacted by the drought because a heat wave that occurred simultaneously with the drought during summer 1988 caused 80-160 heat wave-related deaths in Kentucky.

News articles also reported on other drought impacts besides those on agriculture and water supplies. The Lexington Herald-Leader (1988) published an article about the impacts of fires and drought on trees across the state. The Kentucky Division of Forestry stated in the article that 2,600 fires had burned 77,000 acres in Kentucky during 1988, and that the summer drought had killed an estimated five million tree seedlings. They also stated that it may take three to five years before the full effect of the drought on the trees is revealed, citing the example of trees showing recent signs of parasite fungi and insect problems that were most likely caused by the drought that occurred in 1983. The Messenger-Inquirer (1988) in Owensboro reported on increased food prices nationwide.
as a result of the drought, including a rise in prices for eggs, turkeys, and chickens. Small businesses, especially landscaping companies, were also negatively impacted because citizens were mowing their lawns far less than during non-drought years (The Daily Independent 1988).

4.1.5 Drought of 1999-2001

January 1999 began with dry conditions across much of the eastern U.S. (with the exception of the extreme Northeast) and wet conditions in much of the Midwest, especially across the Dakotas (Figure 15a). Drought developed and intensified in Kentucky and parts of the Mid-Atlantic states in summer 1999, but by fall drought conditions began shifting westward and southward as regions along the Atlantic entered into a moist spell. The summer of 1999 was particularly hot in Kentucky with temperatures reaching 100°F in July in most locations (U.S. Department of Commerce 1999). In Kentucky, the drought peaked in intensity in December 1999 (Figure 15b). Although drought in the southeastern U.S. intensified, temporary drought relief came to Kentucky in spring and summer 2000 as a moist spell that had developed in the Great Lakes region began shifting southward (Figure 15c). It was not until summer 2001 that most of Kentucky was experiencing more normal conditions (Figure 15d).

Table 5 is a summary of crop conditions in 1999, 2000, and 2001 for tobacco, corn, and soybeans. Overall impacts of drought on those crops were by far the worst in 1999. Persistent dry conditions throughout the entire growing season made for a very disappointing year for tobacco, corn, and soybean farmers. Many farmers took advantage of the corn and soybean crops that were not of good quality by chopping it for silage and
cutting it for hay, respectively. Hay production in 1999 was also significantly down from 1998. Alfalfa hay experienced the lowest production in 16 years (Kentucky Agricultural Statistics 1999-2000). A relatively wet spring in 2000 contributed to a much better crop year than 1999. A brief dry spell in May 2001 temporarily set back burley tobacco and soybeans, while hot and dry conditions in July caused the corn crop to become stressed in western Kentucky, but for the most part 2001 was also a good crop year. The cattle inventory as of 1 January 2000 was down seven percent from 1999 and the smallest inventory since 1962. Drought conditions in 1999 caused a reduction in water supplies, hay, and pasture that caused many producers to sell out or reduce their herds.

Figure 15. PDSI values for (a) January 1999, (b) December 1999, (c) September 2000, and (d) July 2001. Data Source: National Climatic Data Center.
Water supplies were severely impacted during the drought of 1999-2001. Streamflows for 22 out of 33 stations experienced lower flows in 1999 than in 1988, which was the last major drought to occur previous to this one. The Licking River basin was hit particularly hard, and the Kentucky and Salt River basins were also greatly impacted by little rainfall. The city of Falmouth, located in the Licking River basin, suffered from a significant water supply shortage and had to construct a temporary dam to keep water adequately above the system’s intake point. On the Kentucky River, Lock 10 experienced its lowest flow since 1960. This lock is immediately above the intake point for Kentucky-American Water Company, which supplies the greater Lexington area. In some areas, systems were competing for water with farmers using water for agricultural purposes (KYDOW 1999).

<table>
<thead>
<tr>
<th>Commodity</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
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<tbody>
<tr>
<td>Tobacco (Burley)</td>
<td>• Overall decrease in harvested acreage, lower yield than 1998</td>
<td>• Drought problems minor, good growing season for burley tobacco</td>
<td>• Dry May slowed setting of burley tobacco</td>
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<tr>
<td></td>
<td>• July-September hot and dry, did not bring rain that benefits tobacco</td>
<td></td>
<td>• Some parts of the state had limited yields due to dry weather</td>
</tr>
<tr>
<td></td>
<td>• Some harvested tobacco had small leaves and low plant weights</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Stripping slowed due to dry fall</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Overall disappointing sales</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tobacco (Dark)</td>
<td>• Lower fire-cured tobacco production than 1998</td>
<td>• No issues reported related to drought</td>
<td>• No issues reported related to drought</td>
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</table>
Corn
- Limited yields due to hot, dry weather
- Dry summer caused stressed corn crop
- Late-planted corn did not fare as well
- Farmers chopped some corn for silage instead of shelling it for grain because of dry conditions, expected low corn prices, and shortage of forage for cattle
- Lack of soil moisture in June caused some stressed corn crop, but overall an excellent growing season
- Western Kentucky had stressed corn due to dry conditions in July

Soybeans
- Lowest yield in 16 years
- Germination problems due to dry soil moisture in spring
- Dry August caused early planted soybeans to deteriorate
- Some soybeans were instead cut for hay
- Late-planted crop severely hurt
- Spotty dryness produced localized poor soybean crop, but no major problems
- Slow planting in mid-May due to dry soils

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KYDOW prioritized systems to determine which ones were of most concern. Systems were classified as either high priority, priority, or low priority. A system that was a high priority meant that personnel were unaware of the percent of streamflow/days supply remaining, and the system had either evidence of source problems or had requested assistance from KYDOW. As of 2 September 1999, 13 water systems were classified as high priorities and were located in the Big Sandy, Cumberland, Green, Kentucky, and Licking River basins. A system classified as a priority meant that personnel were aware of the percent of streamflow/days supply remaining, and the system was showing evidence of source problems. An additional 13 water systems fell
into this category, representing the Cumberland, Green, Licking, and Ohio River basins. Low priority systems may or may not have been aware of the percent of streamflow/days supply remaining, and they either showed evidence of a few immediate source problems or their problems were only with infrastructure. Ten water systems were classified as low priorities, representing the Big Sandy, Green, Kentucky, Licking, Ohio, and Little Sandy River basins (KYDOW 1999).

Water shortage declarations were issued for various systems throughout 1999, 2000, and 2001, with the majority of them being issued during late 1999 and early 2000 (Figure 16). If a water system is in the advisory phase, voluntary conservation is requested for essential, socially or economically important, and non-essential uses. During the alert phase, non-essential water usage is banned, socially or economically important water usage is restricted, and essential water usage is voluntarily conserved. During the critical phase, even essential water usage can be restricted if the situation calls for it (KYDOW 1988a). During October 1999, 126 water systems were in some phase of water shortage declaration, the most of any other month during the drought. By May 2000, the number of systems that were issued water shortage declarations had dropped to under 30, then gradually diminished until summer 2001 when the drought ended (KYDOW 1999).

An increase in the number of fires and acres burned was another impact caused by the drought of 1999-2001. Figures 56 and 57 in section 4.2.2.5 concerning the impacts on the occurrence of wildfires section reveal that the number of fires that occurred in 1999, 2000, and 2001 was well above the average number of fires per year. A significant amount of acres were burned during those three years as well.
The recreation and tourism industry was also impacted. In 1999, officials at the Kentucky State Fair were expecting a smaller turnout of farmers and garden hobbyists exhibiting plants or other items because many of them did not have very good quality exhibits to show (Kentucky Post 1999a). In Louisville, the Oxmoor Steeplechase, an equine event, was cancelled for the first time since World War II because the hard and dry ground posed a threat to the horses (Lexington Herald-Leader 1999a). The white-water rafting and kayaking season on the Big Sandy River was negatively impacted due to abnormally low water levels (Kentucky Post 1999b). Drought also impacted tourism, although it was not a completely negative impact. Land between the Lakes National Recreation Area experienced an increase in the number of tourists in 1999 compared to 1998, but Mammoth Cave National Park’s number of visitors declined in 1999 from the previous year (Daily News 2000). However, park officials stated that the decrease in tourists could be attributed to economic factors, such as higher gas prices and changing travel patterns.
Damage to infrastructure was also reported by news media. Personnel at Owensboro Municipal Utilities worked overtime hours to repair numerous waterline breaks that were caused by extremely dry ground (Messenger-Inquirer 1999). According to the water operations supervisor, waterline breaks and leaks are more common during the summer, but the issue was exacerbated by drought in 1999. Some homeowners had to deal with damaged foundations because of dry soil sinking and shifting, typically costing each homeowner thousands of dollars in repairs (Courier-Journal 1999a).

Environmental impacts also occurred during the drought of 1999-2001. Wild ginseng grows in eastern Kentucky and was threatened by the drought (Lexington Herald-Leader 1999b). Kentucky is the nation’s leading producer of ginseng, which is popularly known worldwide as an herbal medicine. The already endangered plant became even scarcer after it did not get the rainfall it needed to properly grow. The drought was also blamed for the deaths of 50 mallards on Beargrass Creek in Jefferson County (Courier-Journal 1999b). Biologists at the Kentucky Department of Fish and Wildlife Resources believed that avian botulism poisoning may have been to blame. Botulism is a bacterium that thrives in a deoxygenated environment, which was caused by the excessively hot and dry conditions over the summer of 1999.

4.2 Drought of 2007 – A Case Study

4.2.1 Timeline of Drought Development

At the beginning of 2007, abnormally wet conditions prevailed across the Northeast and Ohio Valley regions, while dry conditions existed in the Southeast (Figure 17a). Throughout the winter and spring, drought intensified in the Southeast, including Kentucky. By May, all Kentucky climate divisions were experiencing drought (Figure
17b). The drought continued to intensify in the Southeast throughout the summer, reaching its peak intensity in Kentucky in August and September (Figure 17c). Abnormally heavy rains came in October and temporarily alleviated drought in all Kentucky climate divisions except the Eastern Climate Division (Figure 17d). However, dry conditions returned in all Kentucky climate divisions except the Central Climate Division to finish out the year. Throughout the duration of the drought of 2007, the Midwest remained abnormally wet. Drought conditions past December 2007 were not examined for the following reasons: 1) the rainfall in October marked the end of a drought episode and created a time period for the drought that was easy to analyze, 2) the surveys concerning impacts on agriculture and water supplies were distributed May 2008 and were intended to analyze the drought period ending in October, and 3) weekly drought reports for 2008 were not available at the time they were needed for analysis.

Figure 17. PDSI values for (a) January 2007, (b) May 2007, (c) August 2007, and (d) October 2007. Data Source: National Climatic Data Center.
KYDOW began publishing weekly drought reports starting 6 June 2007 and ending 7 November 2007. The following text is a synopsis of the development of the drought that was summarized from these weekly reports. The report from June 6 stated that the precipitation deficit had been accumulating since November 2006. KYDOW received reports from 12 water utilities that high water demands were overwhelming their water systems. Water demand was especially high over Memorial Day Weekend. The month of May had an unusual 12- to 15-day period without beneficial rainfall across the state. Precipitation deficits tended to be worse across the southern regions of each of the climate divisions. Regarding streamflows, the U.S. Geological Survey (USGS) real-time stream gauging network was recording record-low daily flows in portions of the Green, Kentucky, Salt, and Licking River basins. For referencing purposes, Figure 18 is a map of Kentucky’s river basins. The Barren River reservoir in Barren County and the Rough River reservoir in Breckinridge County had been lower than normal since mid-March.

Figure 18. Major Drainage Basins in Kentucky. Data Source: Kentucky Geography Network 2007.
The June 11 report stated that a Water Shortage Watch was declared for 61 counties in Kentucky (Figure 19). Moderate to severe drought conditions were present at this time. Although there were no reported shortages at water supply intakes, KYDOW requested that customers implement water conservation measures. Moderate to severe low flows were reported in the Upper Cumberland, Salt, Licking, and Green River basins. The USACE reported that Taylorsville Lake was below normal summer pool. USACE keeps lakes lower during the winter (called winter pool) in anticipation of spring rainfall (Blanton 2009). Lakes are then raised for summer pool in anticipation of drier conditions. Although USACE has a specified schedule for when lakes are raised for summer pool and lowered for winter pool, an existing dry spell or the anticipation of a dry spell may influence USACE’s decisions to alter this schedule. For referencing purposes, Figure 20 is a map of Kentucky’s lakes that are controlled by the USACE.

According to the report from June 18, precipitation deficits for this point in the year ranged from six to ten inches across the state with locally higher amounts. Record-
low daily flows were becoming more numerous. The USACE reported that in addition to Taylorsville Lake, Grayson Lake was below normal summer pool. By the time the June 25 report was released, scattered showers and thunderstorms had fallen across the state, with the Central and Western Climate Divisions receiving the most rainfall. Streamflows in these regions also improved slightly.

![Kentucky Lakes Controlled by the U.S. Army Corps of Engineers](image)

Figure 20. Kentucky Lakes Controlled by the U.S. Army Corps of Engineers. Data Source: USACE 2008.

The last two weeks of June brought cooler temperatures and wetter conditions to Kentucky, slowing the progress of the drought and relieving some of the agricultural impacts. Scattered showers and thunderstorms contributed to slight to moderate improvement in streamflow conditions. However, streamflows were still below normal in most of the streams in the Water Shortage Watch area. Once again, the Central and Western Climate Divisions received a majority of the rainfall, and the 30-day precipitation status improved for the western half of the state.
The July 9 drought report stated that the scattered showers and thunderstorms that occurred over the previous three weeks largely missed the Eastern Climate Division, and parts of southeastern Kentucky were experiencing 12-inch precipitation deficits. The July 16 drought report was similar to the previous week’s report except to say that the 30-day precipitation status had returned to near normal in many parts of the state. It also stated that the southern portions of the climate divisions were still the driest. By July 23, drought conditions had continued to improve as streamflows rebounded in most parts of the state.

By August, the drought in Kentucky was deepening again. Excessively high temperatures prompted weather officials to issue Heat Advisories. The state-averaged temperature for August 2007 was 80.9°F, which was 6.1°F above normal (MRCC 2009). Statewide, this was the hottest August ever recorded since thorough climate record-keeping began in 1895. Precipitation received from scattered showers and thunderstorms in the previous month quickly diminished. KYDOW issued a Water Shortage Warning for Warren County because the Barren River, Warren County and Bowling Green’s primary source for water, reached critically low levels and was the lowest since the completion of the Barren River reservoir in 1963. KYDOW was particularly concerned that water usage would rapidly increase across the state in August because students were returning to school. Despite the deteriorating weather conditions, streamflows were holding up well except for areas in the lower Green and lower Cumberland River basins. At this point in time the precipitation deficit had grown to 8-14 inches in the southern portions of the Western and Eastern Climate Divisions.
The drought continued to intensify throughout August and water systems continued to show signs of stress from the dry conditions. Precipitation deficits reached 16 inches in parts of the Western and Eastern Climate Divisions as the Drought Monitor showed most of Kentucky in severe drought and a small portion of southeastern Kentucky in the extreme drought category (Figure 21). All river basins contained streams that were running “much below normal,” a designation by the USGS that means streams are running at less than 10th percentile for the period of record (Figure 22). Some of the small water-supply lakes were finally showing stress from the drought conditions, so some water utilities began asking customers to implement water conservation measures.

![U.S. Drought Monitor](image)


Beneficial rainfall occurred in mid-August over northern Green, most of the Salt, and portions of the lower Kentucky River basins. This rainfall mostly helped to improve surface conditions, such as pastures, ponds, and urban landscapes, which reduced the
demand for outdoor water use in these regions. However, the Western Climate Division was experiencing a precipitation deficit of 10-18 inches and had only received 17% of normal rainfall during the past 30 days, while the other three climate divisions averaged 77% of normal rainfall. Additionally, the USACE reported that Green River Lake was now lower than normal summer pool.

![Figure 22. Streamflow Conditions for 17 August 2007. Source: KYDOW 2007a.](image)

By the end of August, KYDOW was especially concerned with issues of high water demand, and it appeared that voluntary water conservation measures were ineffective. At this point, KYDOW stated that the drought of 2007 was the most severe drought statewide since 1953. Water supply sources were declining statewide, and flows on the main stem of the Kentucky River had not been that low since 1999. Buckhorn Lake, Yatesville Lake, and Fishtrap Lake joined other lakes that were below normal summer pool.
At the beginning of September, KYDOW issued a Water Shortage Warning for Simpson and Magoffin Counties and extended the watch area to include five more counties (Figure 23). Simpson County was issued a warning because of low flows on the West Fork of Drakes Creek, and Magoffin County was issued a warning because of low flows on the Licking River. Six USGS stream gauges were recording flows at all-time lows for the day the report was written for their period of record. Ten- to 20-inch precipitation deficits were present in the southern portion of the Western Climate Division.

Scattered showers occurred during mid-September that brought temporary drought relief across the state, especially across the Central Climate Division. As a result of the showers, streamflow conditions improved. However, the USACE reported that Cave Run Lake was now below normal summer pool. In late September, the USACE began to issue permits for temporary water withdrawal for uses other than crop irrigation.
KYDOW was most concerned about communities located in the headwaters of the Kentucky, Licking, and Cumberland Rivers that rely on small streams or abandoned underground mine works or wells. Approximately one-half of Kentucky’s stream-gauging network was reporting flows that were less than the 25th percentile, and nearly one-quarter of those were reporting flows that were less than the 10th percentile, or “much below normal”. At this point, low levels of USACE-operated lakes became less of a concern because USACE was about to start lake drawdowns for winter pool.

On October 4, Governor Ernie Fletcher issued a state of emergency because of the worsening drought conditions. The drought had caused an increase in fire occurrence in August and September, which is a time that wildfires do not typically occur in Kentucky. The executive order banned all open burning unless first approved by the Environmental and Public Protection Cabinet. The regions of greatest concern over drought conditions were southeastern and south-central Kentucky because these regions were experiencing the worst rainfall deficits. The October 16 drought report stated that Letcher, Harlan, and Pike Counties were issued Water Shortage Warnings. The warnings were issued because various creeks that supply citizens of these counties were experiencing critical low-flow conditions. As much as 30% of the gauges across the state were reporting flows that were less than the 10th percentile.

The last weekly drought report was issued on November 7. Widespread rainfall with significant short-term precipitation totals statewide occurred October 23-25. This was a very unusual event because the rainfall was not associated with a tropical system. Areas in the Central and Bluegrass Climate Divisions received as much as six inches of rain on October 23. All four climate divisions received more than 100% of normal
precipitation for the previous 30 days. As a result, PDSI values were near normal for all climate divisions except the Eastern Climate Division, some of the small water-supply lakes returned to near-normal levels, and many streams returned to baseflow conditions. KYDOW lifted Water Shortage Warnings for Warren, Simpson, and Pike Counties and lifted the Water Shortage Watch for 19 counties (Figure 24).

Precipitation departures from normal from January to September 2007 cover a wide range of values. Along the Ohio River and in the northern half of the state, precipitation deficits were lower, while in the southern half of the state, deficits tended to be much higher (Figure 25). Table 6 shows August precipitation, cumulative precipitation January-September, and precipitation departures from normal for six selected cooperative observing stations. Note that deficits were highest in Bowling Green and Somerset, which are in the southern portion of the state where drought
persisted the most, while lower deficits can be found across the northern half of the state and along the Ohio River. It is also interesting to note that Lexington was the only city to receive greater than normal precipitation in August.

Figure 25. Precipitation Departures from Normal January-September 2007. Data Source: National Climatic Data Center.

<table>
<thead>
<tr>
<th>Station Location</th>
<th>August Precipitation/ Normal Precipitation (in)</th>
<th>Cumulative Precipitation January-September (in)</th>
<th>Departure from Normal (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bowling Green</td>
<td>0.94/3.44</td>
<td>22.58</td>
<td>-15.83</td>
</tr>
<tr>
<td>Lexington</td>
<td>4.00/3.77</td>
<td>27.50</td>
<td>-8.23</td>
</tr>
<tr>
<td>Louisville</td>
<td>1.61/3.41</td>
<td>25.71</td>
<td>-8.54</td>
</tr>
<tr>
<td>Owensboro</td>
<td>1.31/3.58</td>
<td>29.69</td>
<td>-4.79</td>
</tr>
<tr>
<td>Paducah</td>
<td>1.17/2.99</td>
<td>28.03</td>
<td>-8.85</td>
</tr>
<tr>
<td>Somerset</td>
<td>0.53/3.75</td>
<td>22.76</td>
<td>-16.23</td>
</tr>
</tbody>
</table>


4.2.2 Survey of Impacts

4.2.2.1 Overview

Since drought impacts are not very well documented, it was found that the best method for identifying them was through news reports. Figure 26 is a print screen image of the spreadsheet containing the information about each news article collected.
Figure 27 shows the frequency of reported drought impacts during the time period news articles were collected. It is important to note that some news articles discussed more than one drought impact, so there were more impacts reported than news articles collected. Some impacts were difficult to classify into only one type of impact because they could easily fall into more than one classification. For example, wildfires are classified here as social impacts because the majority of the news articles about wildfire were stressing the issue of safety. However, wildfires could also be environmental impacts because they damage the environment, and they could also be economic impacts if property is lost because of them.
The three major economic impacts reported were impacts on agriculture, recreation and tourism, and small businesses. News reports that discussed drought impacts on livestock were included in the agricultural impacts. Hydrological impacts and damage to animal species make up the environmental impacts reported by media. The social impacts reported were impacts on health and municipal companies. The impacts on health were mostly because of increased fire potential that led to burn bans, and water main breaks or low-quality water that led to boil water advisories. Discussions on low-flow conditions or a shortage of rainfall were classified under environmental impacts, while discussions on water conservation or water restrictions were classified under social impacts.

An analysis of the impacts reported in the sample collection of news articles revealed four major themes that dominated the content of the articles. The articles published in late May to late June suggested that drought was becoming a serious
problem across the state. Agricultural impacts were frequently documented, most likely because drought was occurring during a very important part of the growing season. KYDOW began asking communities to voluntarily conserve water. In late June, some much-needed rain fell across parts of the state, bringing drought relief to many areas. The topic of rainfall in late June dominated the news reports until the middle of July when people began to realize that the rain received in June was not enough to end the drought. The media also reported that burn bans that had been previously put into place were lifted across areas that received rainfall.

By mid July, it seemed that the rainfall in June was nearly forgotten because news reports about worsening drought conditions resumed. The record heat experienced by most of Kentucky during August was frequently reported. Also, reports of the continuing drought conditions contributing to an increased threat of wildfire were prevalent. With the beginning of the fall forest fire hazard season quickly approaching, reports of the threat of wildfire continued through the end of the period. By late August, reports emerged of deer contracting Epizootic Hemorrhagic Disease. This drought impact was frequently noted through the end of September.

This analysis of the media’s drought impact reports served as a starting point for determining how drought most greatly impacts Kentucky. It is evident from the news reports that the majority of Kentuckians are concerned most about drought impacts on agriculture and water supplies; therefore, these impacts serve as the primary focus. On the contrary, there were fewer reports concerning impacts on recreation and tourism, small businesses, plant and animal life, and health. Nonetheless, the less frequently reported impacts were also investigated further because little information is available
about those impacts. The following sections are a discussion of the findings from research on how each of these impacts played a role in the drought of 2007.

4.2.2.2 Impacts on Agriculture

Impacts on agriculture were most frequently reported by the media during the drought of 2007. Agricultural impacts also typically contribute to the majority of economic loss from drought (EDEN 2007). The detrimental effects of drought on agriculture brought about the necessity for facilitating surveys to Kentucky’s agricultural community to obtain further information on the degree of severity the drought placed on agriculture. Unfortunately, after multiple reminders were sent about the surveys, only 12 surveys, or 10%, were returned (Figure 28). The following is a discussion of the overall survey results.

Figure 28. Cooperative Extension Service Offices that Responded to Drought Survey.
Three major impacts were mentioned repeatedly by survey respondents: impacts on livestock, hay, and water availability. Several impacts on livestock were evident during the drought of 2007, such as feed shortages, the increased cost of feed, and having to decrease herd numbers which resulted in lower prices for livestock (Figure 29). Other livestock issues reported include decreased weight gain, loss of milk production, and reproductive inefficiency. To mitigate agricultural drought impacts, farmers sold part of their foundation stock and had extra feed supply on hand.

![Livestock Impacts Observed](image)


Figures 30 and 31 show the inventory of beef cows, as well as cattle and calves, in Kentucky as of 1 January 1970-2008, respectively. Both graphs show that while inventory on 1 January 2008 was not the lowest of the years displayed, the total number of both beef cows and cattle and calves was down from 1 January 2007. According to the Kentucky Agricultural Statistics and Annual Report (2007-2008), the cattle and calves inventory at the beginning of 2008 was down 2% from the beginning of 2007, and the beef cow inventory was down 4% from 2007. These data support information provided
by the survey respondents that herd numbers had to be decreased; however, the annual report does not specifically state that herd numbers were decreased solely because of the drought. It should be noted that the sharp decline in beef cows and cattle and calves in 1999-2000 was attributed to drought conditions because reduced supplies of water, hay, and pasture resulted in farmers’ decisions to reduce herds by selling some of their livestock (Kentucky Agricultural Statistics 1999-2000).

![Kentucky Beef Cows - January 1 (1970-2008)](image)


![Kentucky Cattle & Calves - January 1 (1970-2008)](image)

According to survey respondents, several crops also suffered during the drought of 2007. All 12 of the respondents noted annual and perennial crop losses, as well as income loss for farmers due to reduced crop yields (Figure 32). Damage to crop quality was also noted by 11 of the 12 respondents. Every crop impact listed on the survey was observed by at least two of the respondents, suggesting that the drought of 2007 took a toll on Kentucky’s crops.

The crop mentioned most frequently by respondents that suffered the greatest loss is hay. Problems that were mentioned included a shortage of hay, difficulty finding alternative hay sources, and the increased cost of hay. Hay statistics are divided into alfalfa hay and all other hay because alfalfa hay is typically of higher quality and price than all other hay (Gonzales 2009b). For purposes of this research, all other hay was examined because it accounts for a greater percentage of production than alfalfa hay in Kentucky.

Figures 33, 34, and 35 depict the number of acres harvested, the yield per harvested acre, and total production for all other hay from 1970-2007, respectively.
Despite having harvested the greatest number of acres of hay in 2007 of the 38 years shown (Figure 33), hay yields were significantly down in 2007 at an average of only 1.53 tons per harvested acre (Figure 34). This is comparable to low hay yields in 1988 in which drought also occurred. Overall production was also significantly down in 2007, which was the lowest since 1988 (Figure 35). As a result, the price of hay rose dramatically in 2007 because of the hay shortage, reaching a record high of $105.00 per ton (Figure 36). Other notable peaks on the graph, such as 1983, 1988, and 1999-2000, correspond with years that experienced either abnormal dryness or drought during the spring and/or summer (KCC 2007).


Hay was particularly vulnerable during the drought of 2007 because the devastating late-April freeze destroyed most of the first cutting of hay (Kentucky Agricultural Statistics Annual Report 2007-2008). Additionally, dry conditions severely limited hay yields throughout the summer. As a result, farmers cut about 2.7 million acres of hay, a record-high amount, to compensate for the loss. Also, the drought caused
widespread pasture grass shortages, so farmers needed hay for extra feed, which placed further strain on the short hay supply (Gonzales 2009b).


Figure 36. Average Price per Unit of All Other Hay in Kentucky, 1970-2007. Data Source: National Agricultural Statistics Service.

Figure 37 shows the percentage of pastureland that was rated Very Poor Condition during the 2007 growing season. Pastureland is rated according to the following ranking scheme: Excellent, Good, Fair, Poor, and Very Poor (NASS 2008). Although the graph contains various undulations that reflect periods of precipitation that provided temporary relief from the drought, the graph shows a general upward trend in the percentage of very poor pastureland throughout the growing season. This trend continued until mid-October when heavy rains greatly relieved drought conditions in most of the state.

Figure 37. Percent of Pastureland in Kentucky Rated Very Poor Condition, 2007. Data Source: National Agricultural Statistics Service.
Inadequate water availability was also mentioned frequently by survey respondents. Many farmers found that their ponds began to dry up and had to seek alternative sources of water for livestock (Figure 38). Additionally, farmers had to endure the cost of increased irrigation because of the lack of rainfall. The respondent from Daviess County said farmers were prepared for the drought of 2007 in his county because irrigation was available for more than 20,000 acres of land. On the contrary, four respondents stated their counties were not prepared because farmers needed further irrigation sources. One of those respondents suggested that farmers should have the capability to connect to a county water source as a back-up plan when drought occurs.

Figure 38. A shrinking pond along U.S. Hwy. 31-W South traveling toward Franklin, Kentucky. Photo taken by Megan Ferris, August 2007.

When asked about whether the observed drought impacts were anticipated or unanticipated, only one respondent stated any unanticipated impacts. The respondent from Woodford County said that livestock were sold before planned because of the unavailability of feed, but he also said that the impact fell outside of the Extension
educational programming. If drought is anticipated, four respondents stated that many farmers would decrease their herd numbers and/or maintain a higher supply of feed.

Eleven of the 12 survey respondents said that their CES offices offer assistance (including educational programs, trainings, and/or meetings) to farmers during droughts. These programs may assist farmers with locating alternative water and feed sources, sharing valuable information with other farmers also coping with drought, and a variety of other services. Farmers are encouraged to apply for funds from the Kentucky Soil Erosion and Water Quality Cost Share Program and the Kentucky Soil Stewardship Program – Phase I TSA. Referred to by survey respondents as simply Phase I funds, they assist landowners in addressing soil erosion, water quality, or other environmental problems associated with their farming operations (KYDOC 2009). This program was established in 1994 by the Kentucky General Assembly, and funds are provided partly by them and by the Kentucky Department of Agriculture. Priority is given to animal waste-related problems, agricultural district participants, and any producers who have Agriculture Water Quality plans on file with their local conservation districts.

There are also a variety of funding programs available, such as the Kentucky Agricultural Relief Effort (K.A.R.E.) Program, which utilizes 2008 Kentucky Agricultural Development Funds (KARE Program 2008). There are 18 commercial agricultural investment items eligible for assistance through K.A.R.E. All items are beneficial to the mitigation of various weather-related events, such as drought. Water hook-up to city/county water lines for farm usage; irrigation, equipment, structures, and components; and pasture/grain improvement are examples of items that are eligible for K.A.R.E. funds.
Six of the CES offices encourage farmers to purchase crop insurance to protect themselves from a huge loss if a drought causes a great amount of agricultural damage. According to Richie Thompson (2009) of Farm Credit Services in Bowling Green, there are four primary crops that are insured in Kentucky: tobacco, corn, soybeans, and winter wheat. Regarding tobacco, there are several types that are grown in Kentucky, although burley tobacco is more widely grown across the state. Tobacco tends to be insured the most because it is the primary cash crop grown in Kentucky. According to Thompson, farmers tend to purchase more crop insurance after a drought. He stated that the purchase of crop insurance through his office doubled in 2007 compared to 2006. Thompson also stated that farmers tend to drop crop insurance after several years without a drought. It is also worth noting that the USDA does not consider hay to be an insurable crop in Kentucky, and hay was the crop hit the hardest during the drought of 2007.

Figure 39 shows a comparison between the percent acres of crops insured in Kentucky in 2007 and 2008. In 2008, the percent of acres insured increased compared to 2007 for every commodity shown. While the percent of acres insured increased slightly for most of the commodities, it increased substantially for both dark air-cured and fire-cured tobacco. The change in total acres grown from 2007 to 2008 for each commodity was examined as a reason for the difference in percent of acres insured. It was found that total acres of dark air-cured tobacco remained the same from 2007 to 2008, while the total acres of fire-cured tobacco increased by 1,000 acres. Total acres of soybeans and wheat also increased in 2008, while total acres of barley, corn, burley tobacco, and grain sorghum decreased in 2008. Despite the year-to-year fluctuations in total acres grown for
each commodity, it is evident after discussion with Thompson that the increase in percent of acres insured from 2007 to 2008 is most likely attributable to the drought of 2007.


4.2.2.3 Impacts on Water Supplies

Drought impacts on water supplies were also very frequently reported by media during 2007. Additionally, constituents of KYDOW expressed a desire for further information on how drought impacts water supplies; therefore, a second survey was created to meet that need. The response was fairly good for this survey because 29 of the 96 water suppliers surveyed, or about 30%, responded to the survey. Figure 40 shows the spatial distribution and the size of the population served of responding companies based on their water intake points, and Table 7 identifies each water utility by its number in Figure 40. Figure 41 depicts the number of respondents in each population category that were surveyed. It should be noted that three companies who responded serve a population under 1,000 people, even though the intent was not to survey them. This
suggests that KYDOW records have not been updated since the populations that these
three companies serve fell below 1,000. Because of the ample number of responses, it
was determined that nothing further needed to be done to contact those on the survey list
that were unable to receive the survey.

![Utility Companies that Responded to Drought Survey](image)

*Figure 40. Utility Companies that Responded to Drought Survey. Data Source: KYDOW. (For water utility names, see Table 7.)*

<table>
<thead>
<tr>
<th>Number</th>
<th>Water Utility</th>
<th>Number</th>
<th>Water Utility</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Adairville Waterworks</td>
<td>16</td>
<td>London Utility Commission</td>
</tr>
<tr>
<td>2</td>
<td>Bowling Green Municipal Utilities</td>
<td>17</td>
<td>Louisville Water Company</td>
</tr>
<tr>
<td>3</td>
<td>Bracken County Water District</td>
<td>18</td>
<td>Monroe County Water District</td>
</tr>
<tr>
<td>4</td>
<td>Brownsville Municipal Water System</td>
<td>19</td>
<td>Morgantown Water System</td>
</tr>
<tr>
<td>5</td>
<td>Carrollton Utilities</td>
<td>20</td>
<td>Mountain Water District</td>
</tr>
<tr>
<td>6</td>
<td>Danville City Water Works</td>
<td>21</td>
<td>Nicholasville Water Department</td>
</tr>
<tr>
<td>7</td>
<td>Evarts Municipal Water Plant</td>
<td>22</td>
<td>North Middletown Water Department</td>
</tr>
<tr>
<td>8</td>
<td>Fort Knox Engineering and House</td>
<td>23</td>
<td>Paducah Water Works</td>
</tr>
</tbody>
</table>
Several common themes of drought impacts on water supplies emerged from the surveys (Figure 42). Nearly half of the survey respondents reported increased water usage at some point during the drought, whether it was for only 1-2 months or for several months at a time. Paducah Water (McCracken County) and Georgetown Municipal Water Service (Scott County) experienced increases in water usage during every month of 2007 compared to 2006. Hardin County Water District #2 had increased usage for all months in 2007 except January, April, and July, while Louisville Water Company...
(Jefferson County) saw a water usage increase during the months of May-November 2007. Glasgow Water Company (Barren County) experienced a record 12% increase of water usage in August 2007.

Increased water line breaks, increased expenses (e.g. water line repairs, extra manpower, etc.), water quality issues, and the implementation of water restrictions were also frequently reported by survey respondents. It should be noted that increased revenues, a benefit of drought, were reported by some of the survey respondents.

Abnormally low precipitation totals, especially during the summer, most likely contributed to increased water usage because citizens were filling up swimming pools and watering their lawns.

In addition to the implementation of water restrictions across Kentucky by some municipal companies, KYDOW issued water shortage watches and warnings for various counties throughout the duration of the drought, as discussed in section 4.2.1. A water shortage watch is issued when water supply data (e.g. rainfall levels, streamflow, etc.)
indicate the potential for water shortages, and a water shortage warning is issued when at least one water supply system has entered the emergency phase of water shortage (KYDOW 1988a).

After reviewing the water supply status map in Figure 23, one might infer from the map that water supplies were most stressed in central, southern, and eastern Kentucky, while water supplies in western Kentucky and along the Ohio River did not experience as many problems. However, the map is somewhat misleading because water suppliers in counties that were never issued a water shortage watch or warning, such as Paducah Water, Uniontown Water and Sewer (Union County), and Louisville Water Company, actually reported several issues caused by the drought. Paducah Water and Louisville Water Company draw water directly from the Ohio River, while Uniontown Water and Sewer purchases water from Morganfield Water Works, who draws water from the Ohio River. All three companies reported low/no pressure issues and poor water quality. The USGS stream-gauging network reported below normal flows on the Ohio River during most of June, late July into early August, and mid-September. Figure 43, a map of 28-day average streamflow for Kentucky in mid-June, shows that most streams in Kentucky were experiencing substantial departures from normal flows for that time of year, and much of Kentucky (including along the Ohio River) had slipped into severe hydrological drought (the area shaded in red). In contrast, water suppliers that were under a water shortage watch, such as Southside Water (Lee County) and Brownsville Municipal Water (Edmonson County), did not report any issues caused by the drought.
These observations illustrate the spatial disconnect between where the drought is most severe and where the impacts are most evident. Impacts on water supplies may not necessarily occur where meteorological drought is most severe; it depends on the nature of water flow and the locations of dams and levees. A more in-depth analysis of how Kentucky’s drainage basins are affected by drought deserves further study and will be discussed again in the conclusions.

Water suppliers from three of the six counties that were issued water shortage warnings responded to the survey: Bowling Green Municipal Utilities, Mountain Water District (Pike County), and Evarts Municipal Water Plant (Harlan County). The respondents from Bowling Green Municipal Utilities and Evarts Municipal Water Plant both reported concerns over water shortages, but the respondent from Mountain Water
District stated they had emergency transmission connections to two other large water utilities that prevented them from having serious issues.

Respondents that stated they implemented water restrictions were asked if they were able to quantify a reduction in water usage related to water conservation. All respondents said no. One of the reasons for this response could be that it is difficult to determine whether decreased water usage was directly attributable to the implementation of water restrictions. Another reason for this response could be that citizens primarily ignored the water restrictions. In fact, some people even increase their usage after the implementation of water conservation measures because they feel that their usual unrestricted access to water supplies is threatened (Caldwell 2009b). When asked if their companies publish materials available to the general public concerning tips on water conservation, 69% of the respondents said yes; however, the survey responses regarding quantification of a reduction in water usage related to water conservation suggest that the published materials are not very effective.

Another survey question asked if municipal companies have identified alternative, or backup, water sources. Only 55.2% of the survey respondents stated they had identified an alternative water source that could be used during a drought. The survey respondent representing Prestonsburg City Utilities (Floyd County) stated that having an alternative raw water source may have lessened the impacts of drought on the water supplier. A study on water system interconnections would be very helpful in identifying backup or alternative water sources for municipal companies that do not currently have them.
Survey respondents were asked to compare the impacts from the drought of 2007 to the impacts from the drought of 1999-2001. The majority of respondents, 65.5%, stated that the impacts were about the same, 20.7% of the respondents stated that impacts from the drought of 2007 were worse, and 13.8% of the respondents stated that impacts from the drought of 1999-2001 were worse. Next, respondents who said that one drought was worse than the other in terms of impacts on water supplies were asked to explain their reasoning. The respondents who stated that 2007 was worse cited several reasons to justify their responses (Table 8). The respondent from Nicholasville Water Plant (Jessamine County) said the [Kentucky] river pool was lower in 2007 than it was in 1999-2001, creating further stress on their water supply. Respondents from Glasgow Water Company and Monroe County Water District stated that the population they serve has increased dramatically since 1999-2001, thereby also increasing the demand on the system. The respondent from Glasgow Water Company also said the livestock population they served increased from 1999-2001 to 2007. According to the respondent from Paducah Water, the demand for water was much higher in 2007.

<table>
<thead>
<tr>
<th>Water Utility Company</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nicholasville Water Plant</td>
<td>-Kentucky River pool lower in 2007 than 1999-2001</td>
</tr>
</tbody>
</table>
| Glasgow Water Company          | -Population increase from 1999-2001 to 2007, leading to increased demand on the system  
                                 | -Livestock population served also increased                              |
| Monroe County Water District   | -Population increase from 1999-2001 to 2007, leading to increased demand on the system |
| Paducah Water                  | -Water demand higher in 2007 than 1999-2001                           |

Other respondents believed the drought of 1999-2001 was worse than 2007 (Table 9). Respondents from Hardin County Water District #2 and Harrodsburg Water (Mercer County) said their plant/storage capacity was much smaller in 1999-2001, so they were better equipped to handle the drought of 2007. The respondent from Winchester Municipal Utilities (Clark County) stated that the drought of 1999-2001 was worse in terms of local impact. All of these reasons for one drought being worse than the other are critically important when evaluating vulnerabilities of water supplies to drought. Historical records show that drought periods are sometimes far apart, and some of the above-mentioned factors, such as population change, will fluctuate over time. These factors, and others that were not mentioned here, must be considered when evaluating a water supply’s vulnerability to drought so that water utility companies can be prepared for the impacts that may occur.

<table>
<thead>
<tr>
<th>Water Utility Company</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardin County Water District #2</td>
<td>-Plant/storage capacity smaller in 1999-2001 than 2007</td>
</tr>
<tr>
<td>Harrodsburg Water</td>
<td>-Plant/storage capacity smaller in 1999-2001 than 2007</td>
</tr>
</tbody>
</table>


Finally, survey respondents were asked to offer suggestions for better water management practices during a drought. Five key suggestions were identified by the survey respondents: 1) construction of a dam on the current water source, 2) identification of an alternate water source, 3) improvement of infrastructure, 4) customer education and interaction during times of water conservation, and 5) construction of a
more efficient water treatment plant that has a bigger capacity to treat and store water. The implementation of these ideas emphasize drought mitigation as a more effective practice than drought response and may avoid, or at least lessen, the impacts on water supplies that may arise because of a future drought. However, the issue becomes one of feasibility because the aforementioned solutions require the investment of both money and time.

Constructing a dam and finding an alternative water source may affect other people because it could deprive them of access to their water sources. Both of these solutions would require collaboration with other communities and possibly other water utility companies to determine both the positive and negative impacts these solutions would have on everyone. Additionally, the construction of dams and more efficient water treatment plants, as well as the improvement of infrastructure, would all require the acquisition of funds in order for them to be completed. Time-consuming studies would more than likely need to be conducted to justify the need for these items. Customer education and interaction during times of water conservation may require less money than the other solutions, but it would certainly require one’s dedication of time to this project, as it is not likely to have immediate results.

It was previously mentioned that surveys were distributed according to various classes of population size. One aspect of the study was to determine if the size of the population served by the water suppliers seemed to have any impact on the severity of the issues. Fourteen of the 18 companies serving at least 20,000 people reported increased water usage and demand, water quality issues, or both. The smaller companies seemed especially concerned with water shortage issues. It is certainly evident that the drought
affected water suppliers in multiple ways, regardless of the size of the population they served. Water suppliers serving large and small populations reported water line breaks, water quality issues, increased water usage, and water shortage concerns.

4.2.2.4 Impacts on Recreation and Tourism

The impacts from the drought of 2007 on the recreation and tourism industry in Kentucky were examined. The Kentucky Department of Tourism (KYDT) analyzes tourism data and publishes that data on their website. Figure 44 depicts Kentucky Room Supply for 2005-2007, which measures the total number of rooms available for rent across any given geographic area. According to KYDT (2008), the number of rooms available for visitors in Kentucky increased by 1.2% in 2007 compared to 2006. Figure 45 shows Kentucky Room Demand for 2005-2007, which measures the total number of occupied rooms within the state. Demand for rooms increased by 4.3% in 2007 compared to 2006 (KYDT 2008).

![KY Room Supply (2005-2007)](image)

Figure 44. Kentucky Room Supply, 2005-2007. Source: KYDT 2008.
Occupancy measures the ratio of rooms occupied relative to the number of rooms available in any given region and is expressed as a percentage. Figure 46 shows occupancy by month in 2007 through September compared to 2005 and 2006. The only month in 2007 that was down overall from 2005 and 2006 was September at only 0.6%. Otherwise, occupancy increased overall in 2007. From 2005-2007, occupancy increased on average by 3.1% (KYDT 2008). KYDT also looked at occupancy by tourism region, as depicted in Figure 47. Figure 47 shows that only the Western Waterlands region and the Caves, Lakes, and Corvettes region experienced a decrease in tourism from 2005-2007. These decreases in occupancy occurred from 2005 to 2006 and also from 2006 to 2007.

Mona Juett (2008), Research Coordinator for KYDT, stated that no specific studies on the impacts of drought on tourism have been done, but tourism did increase in Kentucky in 2007. Therefore, she did not see any indications that the drought of 2007 had a significant impact on tourism in Kentucky. However, she did recommend that the USACE be contacted regarding lake visitation data.
<table>
<thead>
<tr>
<th></th>
<th>Current Year</th>
<th>Last Year</th>
<th>2 Years Ago</th>
<th>% (+/-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>42.8%</td>
<td>41.4%</td>
<td>41.3%</td>
<td>3.4%</td>
</tr>
<tr>
<td>Feb</td>
<td>52.1%</td>
<td>50.0%</td>
<td>51.4%</td>
<td>4.2%</td>
</tr>
<tr>
<td>Mar</td>
<td>59.0%</td>
<td>56.6%</td>
<td>55.4%</td>
<td>4.2%</td>
</tr>
<tr>
<td>Apr</td>
<td>60.0%</td>
<td>58.2%</td>
<td>60.4%</td>
<td>3.1%</td>
</tr>
<tr>
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<td>59.0%</td>
<td>59.5%</td>
<td>4.6%</td>
</tr>
<tr>
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<td>66.5%</td>
<td>5.5%</td>
</tr>
<tr>
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<td>65.4%</td>
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</tr>
<tr>
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<td>62.1%</td>
<td>60.5%</td>
<td>2.3%</td>
</tr>
<tr>
<td>Sep</td>
<td>60.5%</td>
<td>60.9%</td>
<td>60.3%</td>
<td>-0.6%</td>
</tr>
<tr>
<td>Oct</td>
<td>—</td>
<td>62.1%</td>
<td>60.9%</td>
<td>—</td>
</tr>
<tr>
<td>Nov</td>
<td>—</td>
<td>54.6%</td>
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<td>—</td>
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<tr>
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<td>—</td>
<td>40.9%</td>
<td>40.1%</td>
<td>—</td>
</tr>
<tr>
<td><strong>YTD</strong></td>
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<td><strong>57.7%</strong></td>
<td><strong>58.3%</strong></td>
<td><strong>3.1%</strong></td>
</tr>
</tbody>
</table>

Figure 46. Room Occupancy by Month in Kentucky, 2005-2007. Note that October, November, and December’s data had not yet been compiled. Source: KYDT 2008.

<table>
<thead>
<tr>
<th></th>
<th>Current Year</th>
<th>Last Year</th>
<th>2 Years Ago</th>
<th>% (+/-)</th>
</tr>
</thead>
<tbody>
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<td>W. Waterlands</td>
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<td>62.9%</td>
<td>64.7%</td>
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<tr>
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<td>50.3%</td>
<td>47.8%</td>
<td>2.8%</td>
</tr>
<tr>
<td>Caves, Lakes, Corv</td>
<td>55.9%</td>
<td>57.7%</td>
<td>60.7%</td>
<td>-3.2%</td>
</tr>
<tr>
<td>Kentucky Derby</td>
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<td>58.2%</td>
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</tr>
<tr>
<td>S. Lakes</td>
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<td>57.0%</td>
<td>52.4%</td>
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</tr>
<tr>
<td>N. KY</td>
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<td>60.6%</td>
<td>6.4%</td>
</tr>
<tr>
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<td>58.4%</td>
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</tr>
<tr>
<td>KY Appalach</td>
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<td>53.9%</td>
<td>4.4%</td>
</tr>
<tr>
<td>Daniel Boone</td>
<td>56.9%</td>
<td>56.6%</td>
<td>56.0%</td>
<td>0.5%</td>
</tr>
<tr>
<td><strong>State of KY</strong></td>
<td><strong>59.5%</strong></td>
<td><strong>57.7%</strong></td>
<td><strong>58.3%</strong></td>
<td><strong>3.1%</strong></td>
</tr>
</tbody>
</table>

Figure 47. Room Occupancy by Region in Kentucky, 2005-2007. Source: KYDT 2008.

Three USACE district offices cover the expanse of Kentucky’s lakes: Louisville, Nashville, and Huntington (Figure 20 on page 68). Monthly lake visitation data from Fiscal Year 2003 (FY03) to Fiscal Year 2007 (FY07) were obtained from each of the district offices. Graphs were produced for each lake to compare visitation data from the
five fiscal years. The USACE fiscal year begins in October and ends in September. The time period of particular interest is during the summer months (June-September) because that is when the drought peaked and also when lake recreation tends to be highest.

The Louisville district office is responsible for Barren River Lake, Buckhorn Lake, Carr Fork Lake, Cave Run Lake, Green River Lake, Nolin River Lake, Rough River Lake, and Taylorsville Lake in Kentucky. As the drought intensified throughout the summer of 2007, Barren River Lake experienced fewer visitors in June and July than in any of the four previous years (Figure 48). Nolin River Lake and Rough River Lake also had fewer visitors in June 2007 than in the other years (Figure 49 and Figure 50, respectively). According to Keith Chasteen (2009) of the USACE Louisville district office, Barren River Lake and Rough River Lake most likely experienced fewer visitors during the summer of 2007 because of the drought conditions. However, he mentioned that other factors, such as economic issues and high fuel prices, may have also contributed to lower lake visitation. Chasteen stated that the Louisville district office has not studied anomalies in the data that occur from year to year, so a number of explanations for anomalies in the data are possible.

The Nashville district office is responsible for Dale Hollow Lake, Lake Barkley, Lake Cumberland, Laurel River Lake, and Martins Fork Lake in Kentucky. Dale Hollow Lake had fewer visitors in May and June 2007 than in the previous four years, although visitation for all five years appears very similar on a month-to-month basis (Figure 51). Lake Cumberland experienced a significant decrease in visitation during the spring and summer of 2007 compared to the previous four years (Figure 52). According to Dena Williams (2009) of the USACE Nashville district office, this anomaly may have been
caused by a poor economy or the lake drawdown. The lake drawdown occurred because of a leak found in Wolf Creek Dam, which led to the decision that the USACE would maintain the January 2007 680-foot water level throughout the year (USACE 2008). Although the drought may have contributed to the anomaly by causing even less visitation during the spring and summer of 2007, there have not been any studies conducted by the USACE Nashville district office to support that hypothesis.

Figure 48. Visitation at Barren River Lake, FY03-FY07. Data Source: USACE Louisville District Office 2008.

Figure 49. Visitation at Nolin River Lake, FY03-FY07. Data Source: USACE Louisville District Office 2008.
Figure 50. Visitation at Rough River Lake, FY03-FY07. Data Source: USACE Louisville District Office 2008.

Figure 51. Visitation at Dale Hollow Lake, FY03-FY07. Data Source: USACE Nashville District Office 2008.

Figure 52. Visitation at Lake Cumberland, FY03-FY07. Data Source: USACE Nashville District Office 2008.
The Huntington district office is responsible for Dewey Lake, Fishtrap Lake, Grayson Lake, Paintsville Lake, and Yatesville Lake in Kentucky. The only lake that experienced a significant decrease in visitation during the summer of 2007 compared to the previous four years was Fishtrap Lake (Figure 53). Visitation was much lower at Fishtrap Lake during July and August 2007. According to Rodney Holbrook (2009) of the USACE Huntington district office, there are no data that suggest the lower visitation during summer 2007 can be attributed to the simultaneously-occurring drought. He explained that several factors, such as the economy or the weather, may have been more to blame for low visitation during that time.

![Visititation at Fishtrap Lake, FY03-FY07](image)

Figure 53. Visitation at Fishtrap Lake, FY03-FY07. Data Source: USACE Huntington District Office 2008.

Barren River Lake State Resort Park, located in south-central Kentucky, was examined as a case study. According to Monica Conrad (2008), the park’s manager, the lower water level was the biggest impact noted in the park. The low water level caused problems for boaters and led to the closing of the beach used by local residents, campers, and lodge guests. Conrad also suggested that some of the park’s trees may eventually show signs of stress from the drought, although it would be difficult to determine if the
stress occurred because of the drought or the late April freeze that occurred in the same year. Conrad stated that the number of tourists coming to the park did not seem to be affected significantly by the drought.

Golf courses are often affected by drought because maintenance personnel typically increase their efforts to make the courses aesthetically pleasing when there has been very little rain. The City of Bowling Green Golf Division maintains three golf courses: CrossWinds, Riverview, and Paul Walker. According to David Evans (2008), Recreational Staff Assistant for the City of Bowling Green, the fairways at Riverview and Paul Walker are not watered, but the fairways at CrossWinds are watered using a pumping station located at the Barren River. Figure 54 shows water withdrawals in gallons for 2005-2007. Except for December 2005, CrossWinds was not open December-February of each year, so the fairways were not watered. It is evident from the graph that a great deal more water was used to water the fairways in July and August 2007 than in 2005 or 2006. Additionally, more water was withdrawn in 2007 than in 2006 in every month except April and the months when the golf course was closed. Excessive watering to make up for the lack of precipitation in 2007 most likely had a negative financial impact on the City of Bowling Green.

Compare Figure 54 to Figure 55, which shows precipitation totals for 2005, 2006, and 2007 measured by a rain gauge at CrossWinds Golf Course. The data show lower precipitation totals in July and August 2007 that correspond to higher water withdrawals during those same months. According to Angie (2008), Office Assistant for the City of Bowling Green Golf Division, participation and revenue were not really negatively affected by the drought. In fact, she stated that because many golfers still participate as
long as it is not raining, dry days can boost participation. Higher participation leads to higher revenue, so it appeared that the drought did not negatively affect business at any of the city’s golf courses. It should be noted that CrossWinds Golf Course is a municipal course and that the majority of people who play golf there are from the area. The resort-type golf courses in Kentucky may have experienced fewer tourists because of the drought but were not examined in this research.

![CrossWinds Golf Course Water Withdrawals, 2005-2007](image)

**Figure 54.** CrossWinds Golf Course Water Withdrawals, 2005-2007. Data Source: City of Bowling Green Golf Division 2008.

![CrossWinds Golf Course Precipitation Totals, 2005-2007](image)

**Figure 55.** CrossWinds Golf Course Precipitation Totals, 2005-2007. Data Source: City of Bowling Green Golf Division 2008.
Based on the information provided by personnel from KYDT, USACE, Barren River Lake State Resort Park, and the City of Bowling Green, it is not directly evident that the drought of 2007 had a major impact on recreation and tourism in Kentucky. Despite low water levels and high temperatures during the latter part of the summer, people still visited lakes across the state and participated in recreational activities. In many cases, there were more visitors to lakes and golf courses despite the ongoing drought conditions. On the contrary, more money was spent watering fairways on golf courses, and the environment has already shown some stress due to the drought. Additionally, it was found that the USACE district offices representing Kentucky have not analyzed their lake visitation data to determine if drought played a role in decreased visitation. Therefore, it is important that visitation records and records of extra money spent during drought years continue to be kept, and analyses should be performed on the data after drought years to determine if drought has negatively affected recreation and tourism. This information may help constituents of the aforementioned organizations determine how to either allocate funds or implement proper measures to lessen the impacts of drought on the recreation and tourism industry.

4.2.2.5 Impacts on the Occurrence of Wildland Fires

The occurrence and the extent of wildland fires often increase when drought conditions prevail; therefore, Kentucky forest fire statistics from the Kentucky Division of Forestry (KYDOF) were analyzed from 1998-2007, with a particular focus on 2007. According to Michael Harp (2008), Fire Management Program Specialist for KYDOF, a wildland fire is defined as any land that is capable of sustaining and carrying fire, including forested land and grown up fields. KYDOF will respond to wildland fires on
federal public or private lands, except for fires on military bases. However, KYDOF does not log fire reports on federal fires that are fought by the United States Forest Service (USFS), even if the USFS asks for KYDOF’s assistance. Therefore, the data used to generate graphs and maps in this section are KYDOF fire reports from only private or state-owned land, so federal fire data were not analyzed in this research (Harp 2008).

Figure 56 shows the number of wildland fires reported in Kentucky by KYDOF from 1998 to 2007. The average number of fires per year is 1,447 (KYDOF 2008a). The graph shows that while 2007 did not report the most fires during the 10-year period, it does rank third among the years shown as 1,956 fires were reported. Only 1999 and 2001 had more wildland fires. It was previously discussed that drought was occurring in Kentucky during those years (KCC 2007). A further discussion of the relationship between dry conditions and acres burned during the 1999-2001 time period is forthcoming.

![Wildland Fires in Kentucky, 1998-2007](image.png)

Figure 56. Wildland Fires in Kentucky, 1998-2007. Data Source: Kentucky Division of Forestry.
Figure 57 depicts acres burned from wildland fires in Kentucky from 1998 to 2007. In 2007, 52,506 acres burned from wildland fires. The years 2005 and 2006 were very similar because 51,586 acres and 49,759 acres burned, respectively. However, a considerably larger number of acres burned in 1999, 2000, and 2001. In 2001, 178,925 acres burned, which was more than 2005, 2006, and 2007 combined. It is reasonable to suggest that the presence of drought conditions during 1999-2001 may have exacerbated the spread of wildland fires. Conditions were so dry during this time period that many crown fires and underground fires occurred (Harp 2008). Crown fires are fires that burn standing live trees from bottom to top very rapidly, and underground fires are fires that burn the tree roots several feet underground. It is very difficult to extinguish these types of fires, and KYDOF only has equipment to fight fires up to five feet underground. Additionally, firefighters became very fatigued after fighting numerous fires, negatively affecting their decision-making abilities, thus slowing response times (Harp 2008).

![Figure 57. Acres Burned from Wildland Fires in Kentucky, 1998-2007. Data Source: Kentucky Division of Forestry.](image-url)
Kentucky’s spring forest fire hazard season is February 15 – April 30 and the fall forest fire hazard season is October 1 – December 15 (KYDOF 2008b). Figure 58 compares wildland fires by month in Kentucky for the years 2003-2007. During a typical year, it is expected that the peaks on the graph would occur during the spring and the fall forest fire hazard season. At first glance, it is evident that the peaks did occur during the forest fire hazard seasons for each year displayed. The three months that had the most fires (November 2005, March 2006, and March 2007) all experienced statewide, below-normal precipitation totals for those months (MRCC 2009).

![Wildland Fires by Month, 2003-2007](image)

Figure 58. Wildland Fires by Month, 2003-2007. Data Source: Kentucky Division of Forestry.

It is interesting to note that in 2007 (the black line), the occurrence of wildland fires was considerably higher during August and September than any of the other years during those months. In August and September 2007, 119 fires and 248 fires were reported, respectively. This information provides evidence that August and September 2007 were not typical months because a large number of fires occurred during these two months that did not occur during either of the forest fire hazard seasons. This anomaly
suggested the need for examination of weather conditions during this time period. One might have expected this trend to continue into October, but record-setting rains fell during this month, contributing to the general decline in forest fires throughout the end of the year.

Precipitation and temperature data from August and September for the years 2003-2007 may provide an explanation. Figure 59 shows average precipitation that fell across the state of Kentucky during these months for the years 2003-2007. In all years except 2007, precipitation during this time period was above the average of 7.2 inches. However, an average of only 3.72 inches of precipitation fell across Kentucky in August and September 2007, which is 3.48 inches below normal. These excessively dry conditions most likely made wildland very susceptible to the spread of fire.

![State-Averaged Precipitation for August and September, 2003-2007](image)


Temperatures also averaged much higher for these two months in 2007 than in the other years displayed (Figure 60). The average temperature in August and September 2007 was 76.4°F, which was 5°F above the normal temperature of 71.4°F. Excessive
heat, coupled with a considerable precipitation deficit, likely contributed to the unusually large number of fires that occurred during August and September 2007.

The number of fires by county (Figure 61) in 2007 was also examined. It is evident from looking at Figure 61 that eastern Kentucky appears to have had more fire occurrences in 2007. However, the map can be misleading because KYDOF fire response rate is higher in eastern Kentucky than in western Kentucky (Harp 2008). Because of the rough terrain in eastern Kentucky, it is sometimes difficult for firefighters to position their trucks properly to fight a fire, so KYDOF is often contacted for assistance.

Figure 61 can also be a bit misleading because fires tend to be easier to extinguish on the flatter land in western Kentucky, so Volunteer Fire Departments (VFDs) more frequently respond to fires and extinguish them before KYDOF has a chance to respond. If KYDOF does not respond to a fire, then that fire is not reported by KYDOF. According to Craig Peay (2009), Bowling Green/Warren County Deputy Emergency Management Director, a list of wildland fires fought by VFDs is provided to KYDOF. A
survey of VFDs' wildland fire runs shows that just as many wildland fires occur in the western part of the state as in the eastern part of the state (Harp 2008).

Figure 61. Number of Fires by County, 2007. Data Source: Kentucky Division of Forestry.

Figure 62 shows acres burned by county in 2007. Figure 62 looks similar to Figure 61 because more acres of wildland in eastern Kentucky have burned than in any other region of Kentucky. According to Harp (2008), eastern Kentucky’s topography is most likely to blame for more acres burned. Fire travels as much as four times faster for every 10% slope increase compared to flat land, and many of eastern Kentucky’s hills and mountains have slopes of 40-80% (Harp 2008). As one progresses westward across Kentucky, slopes decrease and the topography tends to flatten out (Figure 63).

This study has shown that drought greatly impacts the occurrence and areal coverage of wildfires. It is also evident that during drought periods, there may be an increase of fire occurrences or acres burned during months that typically do not have many fires, such as August and September 2007. It is important that policymakers are aware of this drought impact because unanticipated fire activity may put the lives of
people and their property at stake. Weather conditions should be closely monitored, especially during drought episodes, so that firefighters are prepared to respond to fires quickly and efficiently in order to minimize the dangers that wildland fires may cause.

Figure 62. Acres Burned by County, 2007. Data Source: Kentucky Division of Forestry.

Figure 63. Elevation of Kentucky. Data Source: Kentucky Division of Geographic Information.
4.2.2.6 Impacts on Plant and Animal Species

Impacts on plant and animal species were also reported during the drought of 2007. With regard to plants, it was previously mentioned in the section on recreation and tourism that some trees at Barren River Lake State Resort Park may have become stressed from the drought, but it would be difficult to determine if the stress was from the drought or from the late-April freeze. Additionally, the next section on small businesses discusses landscaping issues caused by the drought, but there were very few news reports concerning drought impacts on plant life because the damage is often not evident until the following spring. Conversely, there were reports of drought impacts on animal life. Impacts were found to be greatest on deer and fish. The following information was gathered from news reports and from the Kentucky Department of Fish and Wildlife Resources (KDFWR).

It is believed that the drought of 2007 played a role in the outbreak of Epizootic Hemorrhagic Disease (EHD) among white-tailed deer (KDFWR 2007a). EHD is the most significant disease of white-tailed deer in the U.S. EHD is caused by the bite of an infected midge and usually occurs in late summer and fall. It has an acute and a chronic form and symptoms may include pronounced swelling of the head, neck, tongue and eyelids; respiratory distress; internal hemorrhaging; lesions in the mouth and in the rumen lining; sloughing hooves; and possible death. Although EHD occurs naturally in deer herds throughout the southeastern U.S., outbreaks are often associated with drought (KDFWR 2007b).

The EHD outbreak in 2007 was the worst in at least 30 years. As of 13 September 2007, all but 10 counties in Kentucky reported suspected cases of EHD.
Dry conditions tend to cause deer to concentrate around water sources, increasing the chance of midges biting infected deer, then transmitting the disease to healthy deer nearby. Deer hunters were concerned over the outbreak because they were afraid of consuming deer infected with EHD, but KDFWR stated that it is safe to eat a deer that is infected with EHD because EHD cannot be transmitted to humans (KDFWR 2007a). Additionally, there was concern over livestock transmitting the disease. Although KDFWR stated that the virus did not appear to be a threat to livestock, several EHD cases were found in cattle in western Kentucky by the end of September 2007 (Lexington Herald-Leader 2007a). Very little is known about the effects of EHD on cattle, but it is believed that cattle do have antibodies to EHD, suggesting frequent exposure (KDFWR 2007a).

Fish were also stressed during the drought conditions in 2007, particularly in parts of the Cumberland River. Water levels had already dropped in the lower Cumberland
River because of seepage in Wolf Creek Dam. Reservoir seepage problems have existed since 1968, resulting in numerous attempts to repair the dam, but most of the projects were only intended to be short-term solutions. Since March 2005, the water level of Lake Cumberland has been kept lower to reduce the risk to people and property until officials can come up with a more long-term solution (USACE 2008).

Lower water levels caused by the Wolf Creek Dam issue have increased the water temperature in the Cumberland River, which has induced stress in cool-water fish, such as striped bass, brown trout, and rainbow trout. The drought of 2007 exacerbated the issue by causing water levels to continue to lower, which further endangered fish in the Cumberland River. Rainbow trout and brown trout typically live in a water temperature that seldom exceeds 70°F (KDFWR 1993). A water temperature of 75.9°F was reported along the Cumberland River in June 2007. According to Benjy Kinman, director of fisheries for KDFWR, a water temperature above 65°F is considered life-threatening to trout (Lexington Herald-Leader 2007b).

According to Brenda Hill (2008) of KDFWR, some fish species may have actually benefited from drought conditions in 2007. It was found in Elkhorn Creek that smallmouth bass are able to spawn better during low rainfall years, resulting in a higher population of smallmouth bass the next year. Hill (2008) stated that fish in small ponds and lakes most likely encounter problems during drought conditions, but fish in bigger reservoirs are probably not as affected by drought.

Although KDFWR does not have any publications regarding drought impacts on fish and wildlife in Kentucky, it is evident from news reports that some fish and wildlife became very stressed or even died because of the dry conditions in 2007. It is important
to understand that drought disrupts the ecological cycle and causes additional impacts on the environment that may not be immediately known. A more complete statistical dataset containing known drought impacts on fish and wildlife, as well as the time and location in which they occur, would contribute to further understanding of how drought directly impacts fish and wildlife in Kentucky.

4.2.2.7 Impacts on Small Businesses

Although small businesses may not have an enormous impact on the economy, they can still be negatively affected by drought (Courier-Journal 2007; Daily News 2007). Based on a sampling of news reports, lawn care businesses and golf courses were most often mentioned as being impacted by the drought of 2007. Because golf courses were covered under the recreation and tourism section, they will not be covered here. Additionally, there is an interest in the effects of drought on car washes, so they were examined as well.

A phone interview was conducted with Scott Oldham, owner of Premium Lawn Care, LLC in Bowling Green. According to Oldham (2008), the following were impacts of the drought of 2007 on his lawn care business: 1) business was down $40,000, or about 35%, in 2007 compared to 2006, 2) from July to September 2007, Premium Lawn Care, LLC only interacted with about 20% of their regular customers for that time of year, and 3) two employees were laid off due to loss of business. The budget was strained because revenue generated from mowing lawns covered expenses, while revenue generated from landscaping was extra profit (Oldham 2008). He also went on to say that he had to decrease his clientele by as much as half during 2008 because Premium Lawn Care, LLC
did not generate enough revenue in 2007 to buy as much equipment and could not support clientele from the previous year. Oldham did mention that there appeared to be a slight spike in revenue after drought conditions subsided, which was most likely due to customers wanting to replace shrubs and re-landscape their lawns, but the extra revenue did little to offset the enormous economic loss.

A phone interview was also conducted with Larry Grove, manager of Bowling Green Super Wash, to discuss possible drought impacts on car washes. Grove (2008) stated that his business was not really affected by the drought of 2007. However, he mentioned that at Bowling Green Super Wash, they treat and recycle their own water, so he guessed that those types of car washes are not usually asked to conserve water. He suggested that other car washes that do not recycle or treat their own water may have to restrict their water use if the water supplies are in peril. Dwight Williams (2009) of Bowling Green Municipal Utilities stated that car washes in Bowling Green were not asked to close during the drought of 2007 because water conservation was voluntary. Mike Gardner (2009), also of Bowling Green Municipal Utilities, said that car washes would be asked to close if mandatory water restrictions were implemented, although car washes that treat or recycle their own water may be allowed to stay open.

These interviews provided basic information concerning the impacts of drought on small businesses. Although small businesses tend to have a relatively minor impact on the economy, they are still an important part of community life and deserve some attention in this matter. While multiple businesses were not surveyed concerning the impacts of drought, the issues that were dealt with by those that were surveyed are considered to be fairly representative of other similar businesses across the state. There
may not be much that policymakers can do to protect small businesses from the impact of
drought, but it is important that they realize the extent to which drought can impact the
local economy.
CHAPTER 5

DISCUSSION

5.1 Discussion of Historical Droughts in Kentucky

The study of historical droughts in Kentucky revealed that a drought does not always originate in the same location, and its duration will vary. Table 10 describes the origin of each of the droughts studied in the analysis. Droughts that have affected Kentucky have originated in all directions and have spread northward, southward, eastward, and westward into Kentucky. The temporal scale of these droughts has also varied. The drought of 2007 was relatively short-lived compared to other historic droughts, such as the longer-duration drought of 1952-55. There is no method to determining whether an ongoing drought in another region will spread to Kentucky, but if it does, the expected duration and severity are unknown.

<table>
<thead>
<tr>
<th>Drought</th>
<th>Origin (before spreading into Kentucky)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1930-31</td>
<td>Eastern Seaboard (especially Northeast) and Upper Midwest</td>
</tr>
<tr>
<td>1940-42</td>
<td>Midwest and Northeast</td>
</tr>
<tr>
<td>1952-55</td>
<td>Southern Plains and Southeast</td>
</tr>
<tr>
<td>1987-88</td>
<td>Ohio Valley and Great Lakes</td>
</tr>
<tr>
<td>1999-2001</td>
<td>Eastern Seaboard (except Northeast)</td>
</tr>
<tr>
<td>2007</td>
<td>Southeast</td>
</tr>
</tbody>
</table>

Table 10. Origins of Historical Droughts in Kentucky.

One method of predicting the development and spread of drought is through analysis of teleconnection patterns. Studies have shown that patterns in drought occurrence may be linked to teleconnections, such as El Niño-Southern Oscillation (Dai et al. 1998; Rajagopal et al. 2000; Boken et al. 2005; Herweijer et al. 2006), Pacific Decadal Oscillation (Englehart and Douglas 2003; McCabe et al. 2004; Balling and
Goodrich 2007), and Atlantic Multidecadal Oscillation (McCabe et al. 2004). El Niño-Southern Oscillation (ENSO) is the warming of the tropical Pacific Ocean, known as El Niño, which coincides with the reversal of surface air pressure at opposite ends of the Pacific, known as Southern Oscillation. Pacific Decadal Oscillation (PDO) is a reversal of ocean surface temperatures that occurs every 20 to 30 years over the northern Pacific Ocean (Ahrens 2005). During the positive phase of PDO, abnormally warm waters exist along the west coast of North America, while cooler waters exist in the North Pacific. The opposite is true during the negative phase of PDO. Atlantic Multidecadal Oscillation (AMO) is an oscillation of sea-surface temperature anomalies that occurs in the North Atlantic Ocean (McCabe et al. 2004). A comparison of teleconnection phases between the drought of 1930-31 and the drought of 2007 reveals that the drought of 1930-31 occurred during an El Niño phase and positive PDO (UIUC n.d.; JISAO 2008), while the drought of 2007 occurred during a La Niña phase and negative PDO (Reynolds and Xue 2008). AMO was in the positive phase for both droughts (KCC 2009). Therefore, drought has occurred during opposite teleconnection phases, making it very difficult to predict drought. The relationship between teleconnection phases and the occurrence of drought in Kentucky would be an interesting study and should be further investigated.

Reports of impacts that have occurred with each of the droughts discussed were more difficult to find for the earlier droughts than for the more recent droughts. It is important to note that just because no reports of a particular impact were found for one of the earlier droughts does not mean the impact did not occur. While impact reports from more recent droughts were expanded to include recreation and tourism, wildland fires, plant and animal species, and small businesses, there were two impacts that were
frequently reported with every drought studied: impacts on agriculture and water supplies.

5.2 Discussion of the Impact of Drought on Agriculture

It is reasonable to suggest that farmers are now better prepared for drought because forecasting techniques have improved and relief funds and crop insurance are now more widely available. However, that does not mean that agriculture is resistant to drought. The same crops have tended to be negatively impacted by drought over time, such as corn, tobacco, soybeans, and hay. The surveys distributed about impacts on agriculture from the drought of 2007 provided valuable insight into the issues that those in the agricultural community have to cope with when drought occurs. The common themes that emerged from survey responses were that farmers must plan for the lack of availability of water sources for irrigation, lack of availability of feed sources, and reduced hay yield to be better prepared for drought. These are some of the same issues farmers dealt with during earlier drought episodes as well.

Overall, the survey respondents conveyed the message that farmers and agricultural stakeholders are aware of the impacts caused by drought, but the degree of severity a drought will reach is unknown, resulting in unanticipated hardships. For example, a farmer may reserve extra feed for cattle that could be used during a drought, but the farmer may not anticipate a severe or long-duration drought that would require a larger supply of extra feed than what was originally set aside. Then the farmer may have to locate extra feed, which may be difficult to find if the drought is widespread, and then
pay a higher price because of the feed shortage. Eventually, the farmer may have to sell some of his foundation stock.

It is also important to discuss trends in agriculture that have changed across the U.S. throughout the last century that may impact agriculture’s vulnerability to drought. Perhaps the most obvious trend is away from small, family-owned farms, and toward large-scale, industrialized farms (Hart and Mayda 1998; Ramsey et al. 2005; Gonzales 2009b). World War II brought about the need for mass food production to fuel the war effort, and by the 1950s, advanced machinery and pesticides led to a substantial surplus of maize (corn) and soybeans (Troughton 2005). By the mid-1960s, soybeans, sorghums, and alfalfa had emerged as increasingly important crops, while production of oats, clover and timothy (types of hay), and cotton had generally declined (Anderson 1970). Shifts in crop production have most likely been caused by various federal programs and subsidies that are used to control the acreage and production of crops. Additionally, global crop production and prices also affect these trends (Thompson 2009).

The number of farms that keep cattle, dairy cows, hogs, and chickens has also generally declined over time and most of the operations are now confined to a much smaller number of farms (Figure 65). The decline in farms that have hogs, dairy cows, and chickens may be attributed to the increasing commonality and convenience of farmers purchasing milk, butter, eggs, and meat from supermarkets instead of producing these goods for self-consumption (Hart and Mayda 1998). The decline in cattle is not as great as hogs, dairy cows, and chickens because cattle can ingest roughages (fibers) that other types of livestock cannot ingest, and keeping cattle requires little time and effort.
These trends will undoubtedly change the way that agriculture is impacted by drought. It is important that policymakers, as well as stakeholders, are aware of the changing patterns of agriculture so that they can plan for possible impacts before a drought occurs. A discussion of the changing vulnerability of agriculture to drought, as well as recommendations to policymakers, will be addressed in the conclusions.

Two other issues to consider that relate precipitation patterns to agriculture are the presence of agricultural contaminants in groundwater, and waste management issues from livestock, chicken, and swine operations. The source and transport of agricultural contaminants are highly dependent on the relationship between climate, hydrogeology, and seasonal land use (Kambesis 2007). Precipitation patterns may also create issues concerning waste from livestock, chickens, and swine because the waste can contain high amounts of chemicals, such as phosphorous or nitrogen (Gonzales 2009a). However, very little information has been found concerning these relationships, suggesting the need for further study.
5.3 Discussion of the Impact of Drought on Water Supplies

Impacts on water supplies were frequently discussed in synopses of the historical droughts that were studied. At some point, all river basins have been impacted by drought, although the Kentucky and Licking River basins were identified as being most severely impacted during the droughts of 1999-2001 and 2007. Communities in these basins mostly rely on surface sources. Communities located in the headwaters of these basins tend to be more vulnerable to drought because they cannot rely on upstream rainfall for drought relief. Communities that are downstream will benefit from rainfall that occurs in the headwaters of the stream. The Kentucky River basin in particular is also highly populated, so the demand for water is high (Figure 66).

![Population by Drainage Basin, 2000](image)


In southeastern Kentucky, many communities rely on groundwater for their water supply (GWPC 2007). Figure 67, a map of surface and groundwater withdrawal sites,
shows that groundwater is an important source of water in southeastern Kentucky. Many communities in southeastern Kentucky use wells to tap into the groundwater. Wells can quickly dry up if there is little rainfall to replenish them. These communities tend to also be vulnerable to drought, especially if households and businesses are not connected to a municipal or county water line.

Water supplies in northern and far western Kentucky tend to not be as vulnerable to drought. With the exception of the drought of 1987-88, the Ohio, Tennessee, and Mississippi River basins have not been as greatly impacted by drought. These basins are drained by rivers that are much larger than some of the rivers in the interior of Kentucky, so they do not tend to have as many water shortage issues. Additionally, groundwater is a very important supply of water in far western Kentucky and along the Ohio River (Figure 67). Alluvial deposits exist in the Ohio and Mississippi River valleys that supply many communities with water (GWPC 2007). Karst areas also exist in parts of Kentucky that supply groundwater to communities (Figure 68). Some of the most extensive karst aquifers in the state exist in far western Kentucky. However, it was mentioned in section 4.2.2.3 concerning impacts on water supplies that water systems on the Ohio River experienced low/no pressure and water quality issues. Although these basins may not deal with water shortage issues, they certainly are not resistant from drought. The availability of groundwater in karst areas is also sometimes highly variable and groundwater may not be reliable during a drought.

The drought of 1987-88 prompted officials to revise the Kentucky Water Shortage Response Plan, as discussed previously in the text. Although this plan is not comprehensive, it provided local water officials with a plan for coping with drought-
related issues. The plan has two goals: 1) long-range water supply planning, and 2) local water shortage response planning (Caldwell 2009c). It outlines a protocol for local communities to follow during drought. Since the implementation of the plan, local water officials have been able to communicate with other officials at both the local and state levels using the same protocol and plan of action.

Figure 67. Surface and Groundwater Withdrawal Sites. Source: Downs and Caldwell 2007.

Figure 68. Areas of Karst Potential in Kentucky. Source: KGS 2004.
5.4 Discussion of Drought Planning in Kentucky

The Water Shortage Response Plan proved to be very beneficial during the droughts of 1999-2001 and 2007, but it does not address the protocol that other agencies should follow during a drought. At the state level, the primary actions have been to monitor developing drought conditions, distribute regional alerts, and assemble groups of people to share information and concerns about the drought. Communication between stakeholders has been somewhat disconnected and most agencies have had their own method of coping with drought. State water officials realized there was a need for collaboration at the state level between various agencies during a drought. It was also realized that taking a proactive approach to drought instead of a reactive approach would be a better solution to long-term planning for drought. Therefore, in 2008, the first comprehensive drought plan in Kentucky was introduced.

The task of developing a comprehensive state drought plan that emphasizes mitigation practices was given to the Energy and Environment Cabinet (EEC). Drafting of the plan began April 2008 and was completed December 2008 (Caldwell 2009c). The plan was then submitted to the Legislative Research Commission as Senate Joint Resolution 109, although it has not yet been formally adopted. Although many existing state drought plans (including plans from other countries) were consulted, the format, scope and purpose, and response actions of Kentucky’s plan were mostly influenced by plans from Hawaii, Connecticut, Massachusetts, Maryland, Virginia, Georgia, North Carolina, Minnesota, Oklahoma, New Mexico, and Missouri (Caldwell 2009c). Most state plans have established multi-agency steering committees that are responsible for state drought response and preparedness actions and smaller committees that focus on
particular response and mitigation activities (Caldwell 2009d). The biggest difference
between plans is how they address mitigation planning, if it is even addressed at all.
Mitigation planning strategies included in Kentucky’s plan were heavily influenced by
plans from Hawaii and New Mexico. Kentucky’s plan is unique from many state plans
because it outlines specific drought mitigation strategies that should take place during
times between droughts, and it fits well with the Kentucky Division of Emergency
Management’s hazard mitigation planning initiative. Since the drafting of the state
drought plan, Kentucky has not experienced a drought. If the plan is adopted, it will be
truly tested when the next drought occurs.

The plan calls for the coordination of the Kentucky Drought Mitigation Team
(KDMT). The purpose of the KDMT is to coordinate state and federal agencies to
respond to drought, and to develop long-term plans to mitigate drought (EEC 2008). The
KDMT is chaired by the EEC and consists of the following members: Department of Fish
and Wildlife Resources, Department for Public Health, Division of Emergency
Management, Kentucky National Guard, Kentucky Department of Agriculture,
Governor’s Office of Agricultural Policy, Kentucky Infrastructure Authority, Kentucky
Cooperative Extension Service, Kentucky State Climatologist Office, Kentucky River
Authority, and Department of Homeland Security. There are many agencies and
organizations who have been invited to support the KDMT, such as the Kentucky
Geological Survey, National Weather Service, U.S. Army Corps of Engineers, and
anyone with particular environmental or recreational interests. Some of the
responsibilities of the KDMT include reporting directly to the governor concerning
drought issues, preparing a Drought Situation Report of impacted sectors, and identifying
vulnerabilities associated with drought and recommending solutions to mitigate those vulnerabilities.

The KDMT is further divided into four Drought Assessment Teams (DATs): the Climate and Water Resources Data Team (CWRD), the Agriculture and Natural Resources Team (AGNR), the Drinking Water and Public Health Team (DWPH), and the Drought and Water Emergency Team (DWE). The CWRD Team will assume the functions of the Water Availability Advisory Group, which has existed since 1984 and has carried out drought response efforts. The Kentucky State Climatologist Office and the Division of Water are co-chairs of the CWRD Team. The CWRD Team will collect surface water, groundwater, climatic, and meteorological data to assess drought conditions. The AGNR Team is chaired by the Kentucky Department of Agriculture. The AGNR Team is primarily responsible for collecting agricultural data to assess drought and identifying potential drought impacts on agriculture.

The DWPH Team, co-chaired by the Kentucky Department for Public Health and the Kentucky Division of Water, will be concerned with identifying drought impacts that affect drinking water supplies and public health. The Kentucky Division of Emergency Management and the Kentucky Department for Environmental Protection/Division of Environmental Program Support co-chair the DWE Team. The DWE Team will convene only when emergency drought situations occur, such as a water shortage emergency, and will be responsible for identifying locations experiencing emergency water shortages that threaten human health, safety, and sanitation. All four DATs will report their findings to the KDMT, who then reports to the governor (Figure 69).
Drought monitoring is an important component of the plan. For drought planning and response purposes, the 15 Area Development Districts (ADDs) in Kentucky will serve as drought management regions (Figure 70). The primary task given to the ADDs is to integrate drought mitigation measures into their local hazard mitigation plans that were created through the Kentucky Division of Emergency Management. Currently, each ADD has a hazard mitigation plan that identifies hazards that occur in the ADD and ranks them according to risk level. The majority of the hazard mitigation plans have listed drought as a low, or even negligible, risk to their regions. Reasons given for this categorization include perceived little historic frequency of drought occurrence, lack of availability of data concerning the cost of drought, normal climatic variability of drought, and the lack of structural damage caused by drought. These reasons illustrate the problem of the perception of drought compared to the perception of other natural hazards. Incorporating drought mitigation measures into the hazard mitigation plans may increase the awareness of drought as a risk to Kentucky, but data on impacts and costs associated with drought are desperately needed.
State drought response will be defined according to four action levels: Drought Advisory, Level I Drought, Level II Drought, and Level III Drought. Cumulative precipitation will be evaluated after 60, 90, 120, and 180 days, and the percent of normal precipitation that falls during those times periods will help to determine the appropriate drought level (Table 11). The declaration of a Drought Advisory will be determined by precipitation deficits (using Table 11), the Drought Monitor, and the Crop Moisture Index. The Drought Advisory declaration will not be made public; it was designed to be an internal declaration that prompts the convening of the CWRD Team to assess the situation.

<table>
<thead>
<tr>
<th>Cumulative Evaluation Period (days)</th>
<th>Drought Level</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Advisory</td>
<td>Level I</td>
<td>Level II</td>
<td>Level III</td>
</tr>
<tr>
<td>60</td>
<td>&lt; 70%</td>
<td>&lt; 60%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>&lt; 74%</td>
<td>&lt; 65%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>&lt; 77%</td>
<td>&lt; 70%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>180</td>
<td>---</td>
<td>&lt; 75%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The declarations of Drought Levels I, II, and III will be determined by the three indicators used in determining the declaration of a Drought Advisory, as well as data on streamflows and small reservoirs. Drought Level I signifies the official drought declaration. This means that drought impacts are expected to be observed in at least one of the drought management regions. The KDMT will issue a press release regarding the drought declaration and the CWRD and DWPH Teams will be activated. Drought Level II declaration means that drought impacts, some severe, are expected to be observed in all of the affected drought management regions. The AGNR and DWE Teams will both activate and frequent communication will occur among the DATs and with the KDMT. If drought impacts become, or are expected to become, so widespread and severe that they may create drought emergencies, then Drought Level III will be declared. At this point, the DWE Team will have a much bigger role of coordinating with the appropriate state agencies to declare a Governor’s Declaration of Emergency, and the KDMT will work to provide frequent updates to the general public through the facilitation of news releases regarding the emergency situation.

Although the plan was designed for taking action at the state level, local governments also play a role in drought response and emergency declarations. A county-judge executive, a mayor, or another appropriate local official can declare in writing that a drought emergency exists. Local governments also reserve the right to issue water emergency declarations, which may include banning all unnecessary water usage. They can also issue executive orders that ban outdoor burning if conditions have become dry enough to pose an increased fire threat. Local governments are usually advised by
officials at the state level, but sometimes they must act independently from state agencies if they are experiencing localized impacts from drought (EEC 2008).

Perhaps the most important component of Kentucky’s state drought plan is the section on drought mitigation and preparedness. The plan outlines seven actions that represent a mitigation approach to drought management. The first is ensuring data availability for assessing water resources and drought monitoring. This step includes enhancing the USGS stream gauging network, developing monitoring networks for groundwater and surface water, and continued support of the Kentucky Mesonet to improve climate monitoring across the state. The second step is to develop an inventory and projection of the state’s available water resources. This includes determining current and future demand for public water supplies and developing studies to identify the impacts of climate change, natural climatic variations, and climatic extremes on existing water supplies.

The third step is to identify and project possible drought vulnerabilities. In particular, the vulnerability of water supplies will be evaluated in terms of public use, agricultural use, and environmental use. Other actions include increasing interconnections between water systems, identifying areas of potential conflict between agricultural use and public drinking water supplies, and consulting other states’ drought plans that discuss sharing water supplies during water shortages. The fourth step is to identify opportunities to increase the raw water supply to address vulnerabilities, which will possibly involve collaboration with the USACE to use water storage in existing Corps projects. Additionally, the plan suggests investigating further uses of the Ohio
River and other “border” rivers to provide a new source of water for interior regions of Kentucky.

The fifth step calls for improving the effectiveness of the state drought response plan. Recommendations include developing a Kentucky drought index that incorporates natural and socioeconomic impacts to produce an accurate measure of drought severity and a review of the local water shortage response plans. The sixth step involves improving the efficiency of the use of Kentucky’s water resources. The implementation of water conservation efforts, especially in schools, is the primary way to achieve this goal. Finally, the seventh step is to promote public education, awareness, and outreach concerning drought preparedness. The plan suggests getting television, radio, and print media involved by developing a public service announcement campaign that focuses on various drought impact sectors. Also, the establishment of an annual Drought Awareness Week that is modeled after the Severe Weather Awareness Week would undoubtedly raise awareness of the impacts of drought and the importance of water conservation.

The creation of Kentucky’s state drought plan coincides well with NIDIS and the NDMC’s mission of taking a proactive approach to drought planning. Kentucky’s plan makes several recommendations that will take time to complete, and a drought will have to occur before the plan’s thoroughness and effectiveness can truly be tested. Increasing public awareness of drought and educating the public about the importance of water conservation will undoubtedly be a challenging, yet worthwhile, task.
CHAPTER 6

CONCLUSIONS

This study is significant for those with vested interests in drought because it outlines the issues that face policymakers attempting to prepare their communities or jurisdictions for drought. It is evident that drought impacts a wide range of sectors in myriad ways and the best method of coping with drought is to be prepared for it. The following is a discussion of the four research questions presented in the introduction.

6.1 Discussion of Research Questions

What are the drought impacts that affect Kentucky and which ones have the greatest consequences? Drought impacts agriculture and water supplies in Kentucky more than any other sector. This is evident through multiple media reports and drought synopses that have been written on every drought included in the study. The impact on agriculture is mostly an economic concern for farmers who highly depend on farm commodities for income. The impact on water supplies is more of a social concern because adequate water is essential for human life. It is these two sectors that policymakers should focus on when developing a drought preparedness plan. Other sectors impacted by drought that do not get as much attention, but are still very important, include recreation and tourism, wildland fires, plant and animal species, and small businesses. There are likely other impacts of drought that go unreported but are not significant enough to be documented.

How do the impacts caused by the drought of 2007 compare to impacts that have occurred during historic Kentucky droughts? Impacts caused by the drought of 2007 in
Kentucky were very similar to impacts caused by historical droughts. Again, agriculture and water supplies have always been the primary impacts of drought in Kentucky. However, the degree of vulnerability of agriculture and water supplies to drought has changed with time. As agriculture has experienced rapid change over the last century, the vulnerability of agriculture to drought has also changed. For example, agriculture has become generally less vulnerable to drought because of the development of advanced agricultural technology and practices. Examples of these practices will be discussed further in the recommendations.

Drought impacts on water supplies have changed only slightly over time. Poor water quality that prompted health officials to distribute anti-typhoid vaccines was an impact caused by the drought of 1930-31, but advances in medical technology and medicine have eliminated this impact. The vulnerability of water supplies to drought depends on several factors. Water supplies have become less vulnerable as more reservoirs and dams have been built to increase water supplies for certain communities. On the contrary, water supplies become more vulnerable if population served by water supplies increases because higher population places a greater demand on water supplies. Population has been projected to increase at least through 2030 for every drainage basin in Kentucky except the Big Sandy (Figure 71). Population is expected to increase by more than 20% in the Kentucky, Licking, and Ohio River basins from 2000 to 2030. This example illustrates the importance of identifying a region’s vulnerability to drought because some impacts diminish with time while others become greater issues.

There is very little information available concerning impacts other than on agriculture and water supplies caused by earlier droughts, so it is difficult to compare
them to impacts caused from more recent droughts. It is likely that earlier droughts negatively impacted recreation and tourism, the occurrence of wildland fires, plant and animal species, and small businesses, but the consequences of the impacts may have changed with time. Changing travel patterns and economic factors were frequently cited by officials involved in recreation and tourism as possible reasons for more or fewer visitors to certain recreational areas. If fuel prices are high and the economy is in recession, tourists will often travel closer to home or may not travel at all. If a drought is occurring simultaneously, tourism may especially be negatively impacted.

![Projected Population Change by Drainage Basin, 2000-2030](image.png)

**Figure 71.** Projected Population Change by Drainage Basin, 2000-2030. Data Source: Kentucky State Data Center 2007.

*How well are drought impacts documented in Kentucky?* The documentation of drought impacts that occur in Kentucky needs improvement. Currently, the best method of identifying impacts is through reports from news media. However, this is an unreliable method of acquiring information on impacts because reports can be biased.
toward a particular opinion or the topics may be skewed toward the interests of the
general public. Agricultural impacts are documented better than any other impact
because the National Agricultural Statistics Service and the Kentucky Department of
Agriculture compile and report detailed data on agricultural commodities.

Impacts on water supplies are not as well documented. There are official data that
record precipitation, streamflows, lake levels, and groundwater levels across Kentucky,
but they do not properly illustrate the spatial disconnect between a drought’s location and
its resulting impacts. The region experiencing the greatest water shortage issues is often
not the one that has received the least amount of rainfall. For example, a community that
gets its water from a stream relies on rainfall upstream to recharge its water supply. If
rain is not falling upstream to replenish the community’s water supply, the community
can be greatly impacted by drought occurring upstream. Also, water systems are
intricately interconnected and it is extremely difficult to accurately identify which water
systems will endure the greatest impact from a drought. These issues provide an
explanation for why an analysis of water supplies’ vulnerability to drought is a very
necessary component of Kentucky’s drought plan.

Drought impacts on recreation and tourism, the occurrence of wildland fires, plant
and animal species, and small businesses are not documented well at all. The majority of
agencies involved in these sectors that were consulted for this study stated that they had
never conducted drought impact studies. Officials involved with the recreation and
tourism industry in Kentucky seemed least concerned about the effects of drought
because impacts were not immediately evident. Officials involved in the other sectors
were more concerned about the impacts of drought, even if they had little evidence that
drought had greatly impacted them. Drought impact studies would be very useful to each
of these sectors to determine their vulnerability to drought. If officials involved in these
sectors find out they are vulnerable, then they can begin preparing for how to best protect
their sectors from drought.

*Will the implementation of Kentucky’s newly-created drought plan minimize the
severity of drought impacts and prepare citizens for forthcoming droughts?* Kentucky’s
drought plan supports the initiative to become proactive in drought planning and is likely
to be successful if it is adopted. It outlines a very specific procedure for responding to
drought that involves numerous state agencies affected by drought. The mitigation
component describes very specific actions to be taken to plan for drought in Kentucky,
but these actions have not yet been fully implemented and will take time and hard work.
As mentioned previously, a drought has not occurred in Kentucky since the plan was
developed, so the next drought to occur in Kentucky will serve as a pilot study that will
ultimately evaluate the effectiveness of the plan.

6.2 Recommendations

The following recommendations are suggested to policymakers involved in
drought planning for Kentucky. Regarding agriculture, better drought forecasting would
provide farmers with more time to prepare for drought and would lessen, or even
eliminate, the drought impacts discussed by survey respondents. Improved drought
monitoring techniques, such as the increase in the quality and quantity of automated
weather stations, would ultimately enhance accurate short- and long-term drought
forecasting. The Kentucky Mesonet, a network of automated weather and climate
monitoring stations, is currently being developed across Kentucky and will provide
timely information to aid in drought forecasting. Additionally, mitigation efforts, such as connecting to a county water source or purchasing crop insurance, should be strongly encouraged by CES offices.

The implementation of more advanced agricultural technology and practices would provide better protection of agriculture from drought, thereby reducing agriculture’s vulnerability to drought. For example, high-moisture barley silage is often used in Alberta, Canada that is practically resistant to drought conditions (MacLachlan 2005). Double-crop silage, typically done with corn and small grain, is produced from more predictable winter and spring precipitation, and helps protect against unpredictable droughts during the summer (Schwab et al. 2008). Highly-aggregated soils that allow for higher air and water infiltration, soils with high levels of organic matter that hold higher water content, and no-till farming practices that retain soil moisture all help to reduce the impacts of drought on farmland (Sullivan 2002). These types of trends may result in a steady decrease of the vulnerability of agriculture to drought and should be implemented by more farmers.

The persuasion of customers to conserve water during episodes of drought has proven to be a tremendous challenge. A media campaign that emphasizes the importance of water conservation may be more effective than water suppliers’ published materials. The media are more likely to reach a greater number of members of a community and have a greater positive impact on customers’ water conservation practices. If consumers were provided monetary incentives for conserving water, consumers would be more inclined to implement water conservation practices. For example, the city or county government could give tax deductions to consumers for costs incurred from repairing
water leaks. Another option would be for water suppliers to discount consumers’ water bills for attaining a given percentage of reduction. Finally, as a mitigation effort, educational programs about water conservation could be incorporated into P-12 academic curricula that would instill very important values in future consumers.

The response rate of future surveys concerning drought impacts would be dramatically increased if phone surveys were conducted instead of surveys over e-mail. The water supply survey was particularly a problem because there are a number of municipal companies that do not have access to the Internet. Although the response rate on the water supply survey was deemed adequate for the study, a few municipal companies were prevented from participating in the study. Involvement of agency officials representing the group of people being surveyed would also likely increase response rate.

Kentucky cannot be fully prepared for a drought until its vulnerabilities to drought are identified. Conducting an extensive analysis of how various sectors are vulnerable to drought in Kentucky and educating the public on the importance of drought awareness are the most important components of Kentucky’s drought plan and should be addressed first. All sectors should be investigated for drought vulnerability because they are all affected by drought in one way or another. Additionally, it is important that the general public’s awareness of drought and its impacts is raised because they can take measures to conserve water during times when water is becoming scarce. This would lessen the need for restricting or banning water uses that cause hardship or economic loss. Public education programs that start in schools are the best tools for raising drought awareness
because children are the future policymakers and leaders that are faced with the challenges of ensuring a healthy and orderly environment for all Kentuckians.

6.3 Future Research

This study was intended to be a general overview of drought impacts that occur in Kentucky, and it was intended to address how policymakers are planning for drought. There is a great deal more analysis that could be conducted on the drought impacts identified in this research. The most notable is a study of Kentucky’s vulnerability to drought, especially its water supplies. Separate studies can be done on how drought impacts each of the sectors discussed in this research. It is important that gaps in data are filled in to create an accurate representation of the drought issues most important in Kentucky.

Primary impacts caused by drought were mostly the focus of this research. There are secondary, and even tertiary, impacts that occur that are difficult to identify but are often ignored. One example is the increase in food prices caused by the failure of crops to produce adequate yields to supply grocery stores. These types of drought impacts make it very difficult to come up with an accurate figure of financial loss caused by drought. It would be desirable to study secondary and tertiary impacts of drought to determine if the costs and benefits of mitigating them are significant enough to be addressed by policymakers.

Step 10 of the 10-step process of writing a drought plan that was discussed earlier in the text (Figure 7) says to evaluate and revise the plan. After the next drought occurs in Kentucky, research should be done to evaluate the state drought plan to identify
potential weaknesses or deficiencies in the plan. Those weaknesses and/or deficiencies should be immediately resolved so that they are not recurring issues. This should be done after every drought occurrence. Drought vulnerability in a particular sector may change from one drought occurrence to another and the plan should be periodically updated to reflect those changes.

Finally, KYDOW personnel have discussed the possibility of developing a drought index specifically for Kentucky. As mentioned previously, most drought indices are generalized and may not be appropriate to use everywhere. More recently, drought indices that are specific to a region have been developed to address certain needs that are not fulfilled by other drought indices. The task of developing a drought index specifically for Kentucky would be challenging due to the lack of homogeneity of soils, geology, and climate patterns across the state. However, if thorough research is conducted that identifies all pertinent variables that should be considered for calculation of the index, a Kentucky drought index may prove to be a very useful tool for early drought detection and monitoring.

Kentucky’s policymakers are faced with challenges presented by the ambiguous nature of drought that cannot be resolved without a thorough examination of how drought impacts various sectors. Additionally, understanding how the impacted sectors are vulnerable to drought is the key to minimizing the consequences of the impacts and preparing for drought. Kentucky’s proposed state drought plan offers myriad ways to enhance the monitoring, response, and mitigation of drought, and if it is implemented, the plan will hopefully inspire Kentucky’s citizens to participate in reducing the impacts that droughts cause for years to come.
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APPENDIX A

Survey of Impacts Resulting from Kentucky Drought of 2007
Impacts on Agriculture

(Note: This survey was created online using a software program. The survey has been retyped for formatting purposes.)

Questions marked with a * are required.

*1. Project Title: Drought Impacts and Mitigation Strategies in Kentucky (later changed to A Survey of Drought Impacts and Mitigation Planning in Kentucky)
   Investigator: Crystal Bergman, Geography & Geology, (***) ***.**** (phone number deleted for privacy purposes), crystal.bergman@wku.edu
   You are being asked to participate in a project conducted through Western Kentucky University. The University requires that you give your consented agreement to participate in this project. The investigator will explain to you in detail the purpose of the project, the procedures to be used, and the potential benefits and possible risks of participation. You may contact her with any questions you have to help you understand the project. A basic explanation of the project is written below. Please read this explanation and discuss with the researcher any questions you may have. If you then decide to participate in the project, choose “I Agree,” and then proceed with the study. If you wish to not participate, choose “I Disagree” and simply log out of the study.

1. Nature and Purpose of the Project: This research involves an analysis of how drought impacts the state of Kentucky and how Kentucky plans for and responds to drought. It will identify strengths and weaknesses of Kentucky’s drought plan and will also include a case study of the drought that occurred in 2007. Because agriculture is greatly impacted by drought, a survey is being conducted to determine anticipated and unanticipated impacts during the 2007 drought, how that drought compares to previous droughts, and how drought response and mitigation can be improved. It is the intention of the researcher to identify the major issues that drought causes and to improve drought response and mitigation so that future droughts are handled more efficiently.

2. Explanation of Procedures: The first page of the study includes this informed consent statement. You will click “I Agree” or “I Disagree” to the informed consent. Clicking “I Agree” means you would like to participate in the study and you can continue with the study. Clicking “I Disagree” means that you do not want to participate in the study, so you can just log out of it. You will then answer the questions in the study, which should take a little time depending on whether or not you will have to look up information to answer any of the questions. After you finish the study, you will click “Submit Survey” to submit the survey. After you submit the survey, you are finished with your contribution to the project.

3. Discomfort and Risks: Due to the nature of the study, there are no known risks to the subjects completing the study.
4. Benefits: You may benefit from the results of the study because you will see as a whole how agriculture was impacted by the drought. You may be able to amend your drought plans/procedures to be better prepared for the next drought that occurs. Upon completion, the study will be available through WKU’s Libraries.

5. Confidentiality: Paper copies of each of the surveys returned will be kept in the office of Stuart Foster, Department of Geography & Geology, in a locked file cabinet for at least three years. After three years, the surveys will be shredded and discarded. After the research project is complete, the surveys will be removed from the Web. The surveys and results are password protected.

6. Refusal/Withdrawal: Refusal to participate in this study will have no effect on any future services you may be entitled to from the University. Anyone who agrees to participate in this study is free to withdraw from the study at any time with no penalty. You understand also that it is not possible to identify all potential risks in an experimental procedure, and you believe that reasonable safeguards have been taken to minimize both the known and potential but unknown risks.

○ I Agree
○ I Disagree

*2. Your name: ________________________

*3. County you serve: ________________________

4. The following is a list of crop impacts from the National Drought Mitigation Center that are often experienced due to a drought. If you observed any of these impacts in your county due to the Kentucky Drought of 2007, simply check the box next to the impact. Please check all that apply.

☐ Annual and perennial crop losses
☐ Damage to crop quality
☐ Income loss for farmers due to reduced crop yields
☐ Reduced productivity of cropland (e.g. wind erosion, long-term loss of organic matter, etc.)
☐ Insect infestation
☐ Plant disease
☐ Wildlife damage to crops
☐ Increased irrigation costs
☐ Cost of new or supplemental water resource development (e.g. wells, dams, pipelines, etc.)
5. The following is a list of livestock impacts from the National Drought Mitigation Center that are often experienced due to a drought. If you observed any of these impacts in your county due to the Kentucky Drought of 2007, simply check the box next to the impact. Please check all that apply.

☐ Reduced productivity of rangeland
☐ Reduced milk production
☐ Forced reduction of foundation stock
☐ High cost/unavailability of water for livestock
☐ High cost/unavailability of feed for livestock
☐ Increased feed transportation costs
☐ High livestock mortality rates
☐ Disruption of reproductive cycles (e.g. delayed breeding, more miscarriages, etc.)
☐ Decreased stock weights
☐ Increased predation
☐ Range fires

6. Please list if possible all economic losses that resulted from the observed impacts.


7. Please list the impacts that occurred that your cooperative extension anticipated and planned for.


8. Were there any impacts that occurred that your cooperative extension did not anticipate and plan for? If so, please list them. If not, proceed to Question 11.

9. What types of issues arose from the impacts that were not anticipated?

10. Which impacts caused more economic loss, those that were anticipated or those that were unanticipated?

- Anticipated impacts
- Unanticipated impacts
- Losses were about the same

11. What actions were taken by your cooperative extension to cope with the observed impacts?
12. Were there any actions that were not taken by your cooperative extension that you think should have been taken to cope with the observed impacts? If so, please explain.

13. How do producers in your county prepare for or mitigate drought impacts?

14. Do you think that those with interests in agriculture in your county were well prepared for the drought of 2007? If so, please explain how they were prepared. If not, please explain how they were not prepared and what they could have done to be better prepared.
15. How would you compare the drought of 2007 to the droughts that occurred in Kentucky in 1999-2000 and 1988 in terms of how the drought affected agriculture?

- 2007 was worse than both 1999-2000 and 1988
- 2007 was worse than 1999-2000 but not as bad as 1988
- 2007 was worse than 1988 but not as bad as 1999-2000
- 2007 was not as bad as 1999-2000 or 1988

16. Please list any existing programs used by those with agricultural interests in your county that help to mitigate drought impacts (e.g. crop insurance, loan programs, etc.)

17. Please list the agricultural impacts that you think are the greatest issues in your county that require more planning/mitigation.

Thank you for your participation. Your input will contribute to the greater understanding of how drought affects agriculture in Kentucky. If you have any questions about this study, please e-mail crystal.bergman@wku.edu.
APPENDIX B

Survey of Impacts Resulting from Kentucky Drought of 2007
Impacts on Water Supplies

(Note: This survey was created online using a software program. The survey has been retyped for formatting purposes.)

Questions marked with a * are required.

*1. Project Title: Drought Impacts and Mitigation Strategies in Kentucky (later changed to A Survey of Drought Impacts and Mitigation Planning in Kentucky)
Investigator: Crystal Bergman, Geography & Geology, (***) ***-**** (phone number deleted for privacy purposes), crystal.bergman@wku.edu
You are being asked to participate in a project conducted through Western Kentucky University. The University requires that you give your consented agreement to participate in this project. The investigator will explain to you in detail the purpose of the project, the procedures to be used, and the potential benefits and possible risks of participation. You may contact her with any questions you have to help you understand the project. A basic explanation of the project is written below. Please read this explanation and discuss with the researcher any questions you may have. If you then decide to participate in the project, choose “I Agree,” and then proceed with the study. If you wish to not participate, choose “I Disagree” and simply log out of the study.
1. Nature and Purpose of the Project: This research involves an analysis of how drought impacts the state of Kentucky and how Kentucky plans for and responds to drought. It will identify strengths and weaknesses of Kentucky’s drought plan and will also include a case study of the drought that occurred in 2007. Because water supplies are greatly impacted by drought, a survey is being conducted to determine anticipated and unanticipated impacts during the 2007 drought, how that drought compares to previous droughts, and how drought response and mitigation can be improved. It is the intention of the researcher to identify the major issues that drought causes and to improve drought response and mitigation so that future droughts are handled more efficiently.
2. Explanation of Procedures: The first page of the study includes this informed consent statement. You will click “I Agree” or “I Disagree” to the informed consent. Clicking “I Agree” means you would like to participate in the study and you can continue with the study. Clicking “I Disagree” means that you do not want to participate in the study, so you can just log out of it. You will then answer the questions in the study, which should take a little time depending on whether or not you will have to look up information to answer any of the questions. After you finish the study, you will click “Submit Survey” to submit the survey. After you submit the survey, you are finished with your contribution to the project.
3. Discomfort and Risks: Due to the nature of the study, there are no known risks to the subjects completing the study.
4. Benefits: You may benefit from the results of the study because you will see as a whole how water supplies were impacted by the drought. You may be able to amend your drought plans/procedures to be better prepared for the next drought that occurs. Upon completion, the study will be available through WKU’s Libraries.

5. Confidentiality: Paper copies of each of the surveys returned will be kept in the office of Stuart Foster, Department of Geography & Geology, in a locked file cabinet for at least three years. After three years, the surveys will be shredded and discarded. After the research project is complete, the surveys will be removed from the Web. The surveys and results are password protected.

6. Refusal/Withdrawal: Refusal to participate in this study will have no effect on any future services you may be entitled to from the University. Anyone who agrees to participate in this study is free to withdraw from the study at any time with no penalty. You understand also that it is not possible to identify all potential risks in an experimental procedure, and you believe that reasonable safeguards have been taken to minimize both the known and potential but unknown risks.

☐ I Agree
☐ I Disagree

*2. Your name: __________________________

*3. Name of your utility company/water district: __________________________

*4. Communities your utility serves: __________________________

*5. Population your utility serves: __________________________

*6. Water source your utility utilizes: __________________________

7. Did you notify or have any contact with the Kentucky Division of Water during the drought?

☐ Yes
☐ No
8. If your utility saw an increase in water usage during any of the months in 2007 compared to 2006, please list the months and the approximate increase in usage. If not, proceed to Question 9.

9. Did you have an increase in the use of water or increase in tap-ons for livestock during the drought? If yes, please estimate the percent increase in water use to livestock watering. If not, proceed to Question 10.

10. Were there any water quality issues encountered by your utility as a result of the drought? If so, please explain. If not, proceed to Question 11.

11. Did your distribution system have any issues with low pressure or no pressure in 2007? If not, proceed to Question 13.

○ Yes
○ No
12. Did your utility ever issue a boil water advisory as a result of low pressure or no pressure?

- Yes
- No

13. Did you have to activate or locate an emergency water supply during the drought (e.g. backup source, interconnections with other systems)?

- Yes
- No

14. Has your utility identified an emergency backup source for your water system?

- Yes
- No

15. Did your water source ever get so low that you became concerned that other users’ withdrawals were threatening your water supply? If so, please explain. If not, proceed to Question 16.

16. Did your utility have to implement water conservation during the drought? If yes, please explain if it was voluntary or mandatory water conservation, or if your utility had to resort to rationing water to customers. If not, proceed to Question 18.
17. Were you able to quantify a reduction in use related to water conservation? If yes, please note the percent of water use reduction you achieved. If not, proceed to Question 18.

18. Do you know of any local businesses directly affected by water shortage measures taken by your community (e.g. car washes closed, golf courses closed, etc.)? If yes, please explain. If not, proceed to Question 19.

19. Did your utility experience an increase in water line breaks as the drought worsened?

☐ Yes
☐ No

20. What financial impacts can you list that your utility encountered as a result of the drought? Please list actual costs if possible.
21. How would you compare water supply issues from the drought in 2007 to issues from the drought that occurred in 1999-2000?

- Impacts were worse in 2007 than in 1999-2000
- Impacts were worse in 1999-2000 than in 2007
- Impacts were about the same

22. If you determined in Question 21 that the impacts were not the same for both droughts, please explain how the impacts were different between the two droughts. If you determined they were about the same, proceed to Question 23.

23. Does your utility publish materials that are made available to customers regarding tips on how to conserve water?

- Yes
- No

24. Is there anything you think could be done in the future to improve your utility’s approaches to water management during a drought? If so, please explain.

Thank you for your participation. Your input will contribute to the greater understanding of how drought affects water supplies in Kentucky. If you have any questions about this study, please e-mail crystal.bergman@wku.edu.