Kentucky Drought Risk Assessment

2023

2023 Kentucky Hazard Mitigation Plan Update- Drought Risk Assessment

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Drought Risk Assessment - Kentucky

Introduction

Kentucky is perceived as a water-rich state with an average annual rainfall of 45 to 50 inches and abundant groundwater and surface water resources. However, Kentucky can experience extended periods of dry weather ranging from relatively short-duration single-season events to multi-year events.

Drought is a natural and recurring climatic feature but unlike other natural disasters, it is not a distinct event that has a clearly defined beginning and end. It is often the result of the interactions between various complex physical and social factors that are difficult to quantify or predict. Ultimately, drought is manifest as an amount or distribution of moisture that is not sufficient to meet the needs of society or the environment and can result from both natural events that decrease supply and from human activities that increase the demand for water.

The impacts to the environment, economy and human health and safety caused by droughts underscore a need to move toward a proactive approach to drought planning and management. The risk of these potential impacts depends on the types of water demands, how these demands are met and the availability of water supplies necessary to meet these demands. This risk assessment provides information to support actions intended to reduce drought risk in Kentucky and aid in identifying *mitigation* actions that reduce the impacts of future droughts.

This Risk Assessment was developed with the help of various valued advisors including those from Kentucky Climate Center at WKU, Kentucky Rural Water Association, US Geological Survey, Kentucky Department of Agriculture, Kentucky Farm Bureau's Water Management Working Group and the Kentucky Water Resources Board.

Type and Location of the Drought Hazard – the nature of drought

Kentucky has experienced five significant drought periods in the past 25 years: 1988, 1999- 2000 and 2007-2008, 2010 and 2012. Each of these droughts brought hardships and various types of damage to Kentuckians, especially the agricultural sector. These droughts also have individual "personalities" in terms of regions affected, how intense they became, how long they lasted and the amount of damage caused. However, these droughts also share common features that distinguish them from normal dry periods:

1. Intensity
   Drought develops only after an extended length of time with abnormally low precipitation, often combined with abnormally high temperatures. This combination of climatic anomalies results in an environment that stresses plants and animals, makes uncomfortable the lives of people living with water shortages, and can sometimes cause structural damage such as shifting foundations and ruptured water lines. In the extreme drought can threaten a community's ability to maintain adequate fire protection, potable water treatment and other essential water uses.

2. Duration
   Kentucky has some level of dry spell in some location in nearly all years. Dry "spells" are termed to reflect a short-duration event most commonly noticed during the hot days of summer, or the warming days of spring. Dry spells are not necessarily droughts, but all droughts begin as dry spells. Unfortunately, and this is especially true for agriculture, a persistent dry spell may cause substantial damage early on in drought development; long before water shortages and problems with public water supplies emerge. Thus, one of the most difficult aspects of dealing with the drought hazard is the ability to distinguish when a dry spell transitions into drought. Given the difficulty, it is best for citizens and officials alike to adopt a proactive approach to lessen the adverse impacts of drought when it invariably occurs.

3. Timing
   Dry spells can occur at any time and so frequently that it is easy to become complacent and assume that rain is just around the corner, because it usually is. When a dry spell lingers and tends toward drought the consequences are determined partly by the timing of drought emergence. Spring droughts can delay the refilling of water supply lakes, accelerate net water loss from soils by rapidly growing plants, reduce hay production and storage, and in general make us more vulnerable to even moderate summer drought.

Summer drought development is most damaging to agricultural interests, reducing crop development and yields and placing hardships on livestock producers when ponds and pastures dry up. Droughts that intensify into the fall generally begin to affect the dependability of sources of drinking water, both surface and groundwater. Historically, most drought-vulnerable communities in Kentucky will experience water shortages during the fall droughts when low flows and low lake levels result from weeks or months of decreased runoff and baseflow in rivers and streams.

Late fall and winter droughts can affect recharge of groundwater and delay or prevent the filing of lakes that typically draw down during summer when evaporation and plant water use (evapotranspiration, or ET) rates exceed rainfall. Severe late fall droughts are not as common in Kentucky and are usually a continuation and often the tail end of a summer drought. However, when a late fall drought develops and persists throughout the winter, serious water supply issues can occur in rivers, lakes and wells. Severe persistent winter droughts increase vulnerability to droughts that may develop the following spring or summer.

Past droughts, especially in the 1980s, have forced communities to enter emergency water restrictions as late (early) as January or February due to lingering winter drought. More recently, the fall/winter droughts of 2016 and 2022 were primarily felt by crop and animal producers as water sources became depleted and pastures fell dormant forcing producers to begin feeding stored hay much sooner than normal.

Defining Drought, Drought Response and Drought Mitigation

There is not a single universal definition of drought. Drought is difficult to describe and many factors determine how and when a persistent dry spell transitions into drought. Most often drought is defined by a combination of several definitions for increasing drought severity that are based on meteorological, agricultural, hydrological and socioeconomic effects.

Meteorological Drought

Meteorological measurements are generally the first indicators of drought development. This category of drought is often defined by a period of precipitation deficit that is outside of a “normal” range over a defined period. The concept of normal is often derived from a 30- year record of daily precipitation measurements at a specific location. Thus, a definition of meteorological drought is regionally specific and presumably based on a thorough understanding of regional climatology.

Agricultural Drought

Agricultural drought occurs when there is not enough soil moisture to meet the needs of a particular crop at a particular time. Agricultural drought develops at some point when meteorological drought persists and is identified by linking the characteristics of a meteorological drought to agricultural impacts. This category of drought can develop quite suddenly and is usually the first economic sector to be affected by drought.

Hydrological Drought

Hydrologic drought refers to deficits in surface and subsurface water supplies. It is measured as streamflow and as lake, reservoir and groundwater levels. There is a time lag between lack of rain and diminished quantities of water in streams, rivers, reservoirs and aquifers. Therefore, hydrological measurements are not the earliest indicators of drought. Drought will not be reflected in declining subsurface and surface water levels until precipitation is deficient over an extended period. Although it is a natural phenomenon, the impacts of hydrological drought are often intensified by human activities and land use.

Socioeconomic Drought

Socioeconomic drought occurs when physical water shortage begins to affect people, individually or collectively. This category of drought is manifested by adverse impacts to the health, well-being and quality of life of the people, or when drought begins to affect the supply and demand of an economic product.

Drought Response

Drought response is the process of taking actions during a drought event to reduce its immediate impacts to the environment or society. The purpose of drought response is to reduce the impacts of drought by making temporary adjustments to normal practices until the threat of drought is relieved by a resumption of normal climatic conditions. Over the long term, a focus on drought mitigation will reduce the severity and level of response that must be implemented.

Drought Mitigation

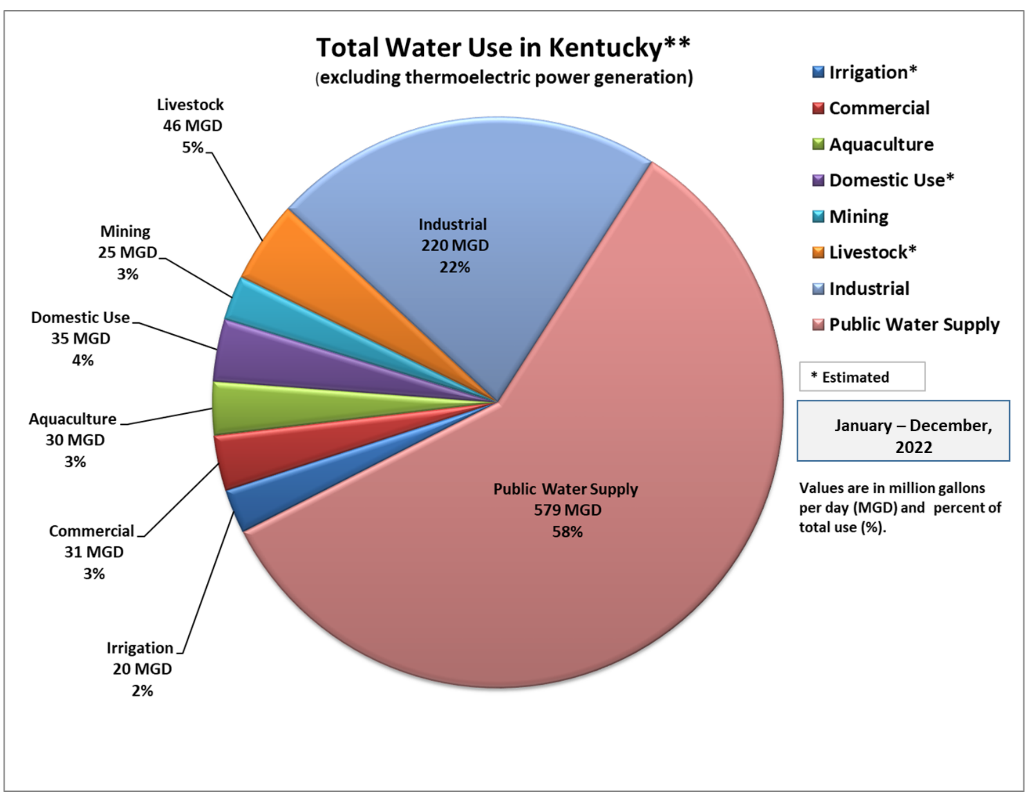
Mitigating drought is the process of taking actions in advance of drought to reduce our long-term risk. The purpose of mitigation and preparedness actions are to reduce the impacts of drought by identifying principal activities, groups or regions most at risk and developing mitigation actions and programs that alter these vulnerabilities.

This assessment can provide data and information that will aid in characterizing and locating the areas and assets most at risk from drought. The focus of this work is on public water supply and agriculture since these water use sectors are vital to Kentucky's human and economic well-being and collectively consume more water than any other water use sector (Figure 1.).

Water Use in Kentucky

On an annual basis, public water supply withdrawals amount to approximately 600 million gallons per day (MGD), followed by industrial withdrawals, livestock and then several lesser uses. Note that the figure for irrigation (20 MGD) is expressed on an annual basis but typically, irrigation will only occur over a period of about three months. The actual water used by irrigation adjusted to a 90-day irrigation season is closer to 80 MGD while the irrigation is actually occurring. Combined, water withdrawn to support irrigation (assuming 80 MGD) and livestock account for about 130 MGD, making agriculture the third largest consumer of water in Kentucky. It should be noted that water used for housed animal operations like dairy or poultry is often supplied by a public water system and is factored into the value for public water supply withdrawals in this assessment.

Figure 1. Water Use (water withdrawn) in Kentucky by sector



Source: Kentucky Division of Water; United States Geological Survey

Methods and Procedures – Drought Hazard, Impacts and Recurrence

The threat that drought poses to Kentucky is difficult to quantify. For purposes of this assessment, a standard definition of risk will be adhered to as closely as possible. The data presented in this document will follow the convention that RISK is a product of a defined HAZARD and EXPOSURE. In the context of drought, the hazard is the drought itself but as will be shown later (Table 4.) drought is a broad, regional hazard that over the long-term recurs on a relatively equal frequency across all regions of Kentucky.

A method to quantify drought as a hazard and its associated risk is to evaluate a proxy (surrogate) for drought risk. In this assessment agriculture will be evaluated with respect to monetary losses using Federal Crop Insurance payments (Cause of Loss data), along with exposure : number of poultry houses at risk, number of hog farms at risk, and number of dairy cattle and beef cattle at risk. For public water systems a drought, exposure variable will consist of numbers of affected people, number of hospital and long-term care beds and a crossover to agriculture with numbers of animals potentially served by each water system.

A summary of the total sales of agricultural commodities published in the UDSA Agricultural Census (2017) gives an indication of what is potentially at risk to some level of drought losses (Table 1.): commodities with a total sales value of nearly $5,800,000,000 in 2017.

Federal Crop Insurance cause of loss data is used for a drought risk proxy because it is one of the few sources of information where monetary damages can be directly attributed to drought. In addition, as of 2022 over 90 percent of corn, soybeans, tobacco and wheat acres are enrolled in the federal crop insurance program (Source: USDA Risk Management Agency). This provides a reasonable estimate of the relative impact that drought has had on what is now over a 3 billion dollar industry.

Table 1. Value of sales of agricultural commodities in Kentucky

ANIMAL SALES	SALES, $
SPECIALTY ANIMAL TOTALS, (EXCLUDING EQUINE)	105,233,000
SHEEP & GOATS TOTAL, INCL WOOL, MOHAIR AND MILK	2,400,000
EQUINE HORSES AND PONIES, MULES, BURROS AND DONKEYS	449,592,000
POULTRY TOTALS, INCLUDING EGGS	1,306,090,000
MILK	166,813,000
HOGS	128,036,000
CATTLE, INCLUDING CALVES	1,002,387,000
OTHER SALES	34,363,000
AQUACULTURE	1,920,000
TOTAL	3,196,834,000
CROP AND PLANT SALES	
FOOD CROP TOTALS EXCLUDING MUSHROOMS, UNDER PROTECTION	2,578,566
VEGETABLE TOTALS, INCL SEEDS & TRANSPLANTS, IN THE OPEN	18,098,000
NURSURY TOTALS	16,853,051
HORTICUTURE	48,139,336
FLORICULTURE TOTALS	51,053,273
FRUIT & NUT TREE TOTALS	3,225,000
WHEAT	101,746,000
TOBACCO	325,278,000
SOYBEANS	868,984,000
CORN	776,828,000
OTHER SALES	328,302,774
TOTAL	2,541,086,000
TOTAL CROP & PLANT SALES	5,737,920,000

Source: USDA Census of Agriculture, 2012

Drought Analysis – Palmer Drought Severity Index

PDSI and Crop Loss Data are used to develop a chronology of drought. The PDSI serves as the drought index that incorporates soil, precipitation and temperature into a physical description of drought severity. The Cause of Loss data serves as a proxy to link drought impacts to drought severity.

The Palmer Drought Severity Index (PDSI) uses readily available temperature and precipitation data to estimate relative dryness. It is a standardized index that spans -10 (dry) to +10 (wet). It has been reasonably successful at quantifying long-term drought. As it uses temperature data and a physical water balance model, it can capture the basic effect of changes in climate on drought through changes in potential evapotranspiration.

The PDSI was developed in the 1960s as one of the first attempts to identify droughts using more than just precipitation data. Palmer developed a method to incorporate temperature and precipitation data with water balance information to identify droughts in crop-producing regions of the United States. For many years, PDSI was the only operational drought index, and it is still very popular around the world.

The PDSI is calculated using monthly temperature and precipitation data along with information on the water-holding capacity of soils. It takes into account moisture received (precipitation) as well as moisture stored in the soil, accounting for the potential loss of moisture due to temperature influences.

PDSI has a timescale of approximately nine months, which leads to a lag in identifying drought conditions based upon simplification of the soil moisture component within the calculations. This lag may be up to several months, which is a drawback when trying to identify a rapidly emerging drought situation. These "flash droughts" can emerge at any time of the year, but have been the most devastating, particularly on agriculture, when they coincide with extreme high temperatures during the summer. Such was the case in past droughts in Kentucky, including droughts in the 1940s, 1960s, 1980s, and most recently in 2007 and 2012.

For purposes of a drought risk assessment the PDSI lends itself very useful due in large part to the relatively long period of record. Current PDSI data available for each climatic division in the U.S. stretches back to 1895, providing more than a century of data to characterize a drought history. For this reason, the PDSI was chosen as the primary indicator to be used in this assessment. The Division of Water has a long history with the PDSI as a drought indicator and for many years it was the only index of drought readily available. Other, more refined indices have emerged in the past two decades, for example, the National Drought Mitigation Center's "Drought Monitor", NASA's "GRACE" satellite moisture index and the Standardized Precipitation Index (SPI). These newer tools are superior in smaller spatial and temporal scales and provide a more real-time aspect to drought monitoring. However, the PDSI has proven to be a reliable tool for identifying droughts, especially in retrospect, lending it particularly useful for purposes of this project.

Table 2. PDSI Drought Categories of Moisture Anomaly

PDSI CLASSIFICATIONS	
> 4.00	extremely wet
3.00 to 3.99	very wet
2.00 to 2.99	moderately wet
1.00 to 1.99	wet
0.50 to 0.99	moist spell
0.49 to -0.99	dry spell
-1.00 to -1.99	mild drought
-2.00 to -2.99	moderate drought
-3.00 to -3.99	severe drought
<-4.00	extreme drought

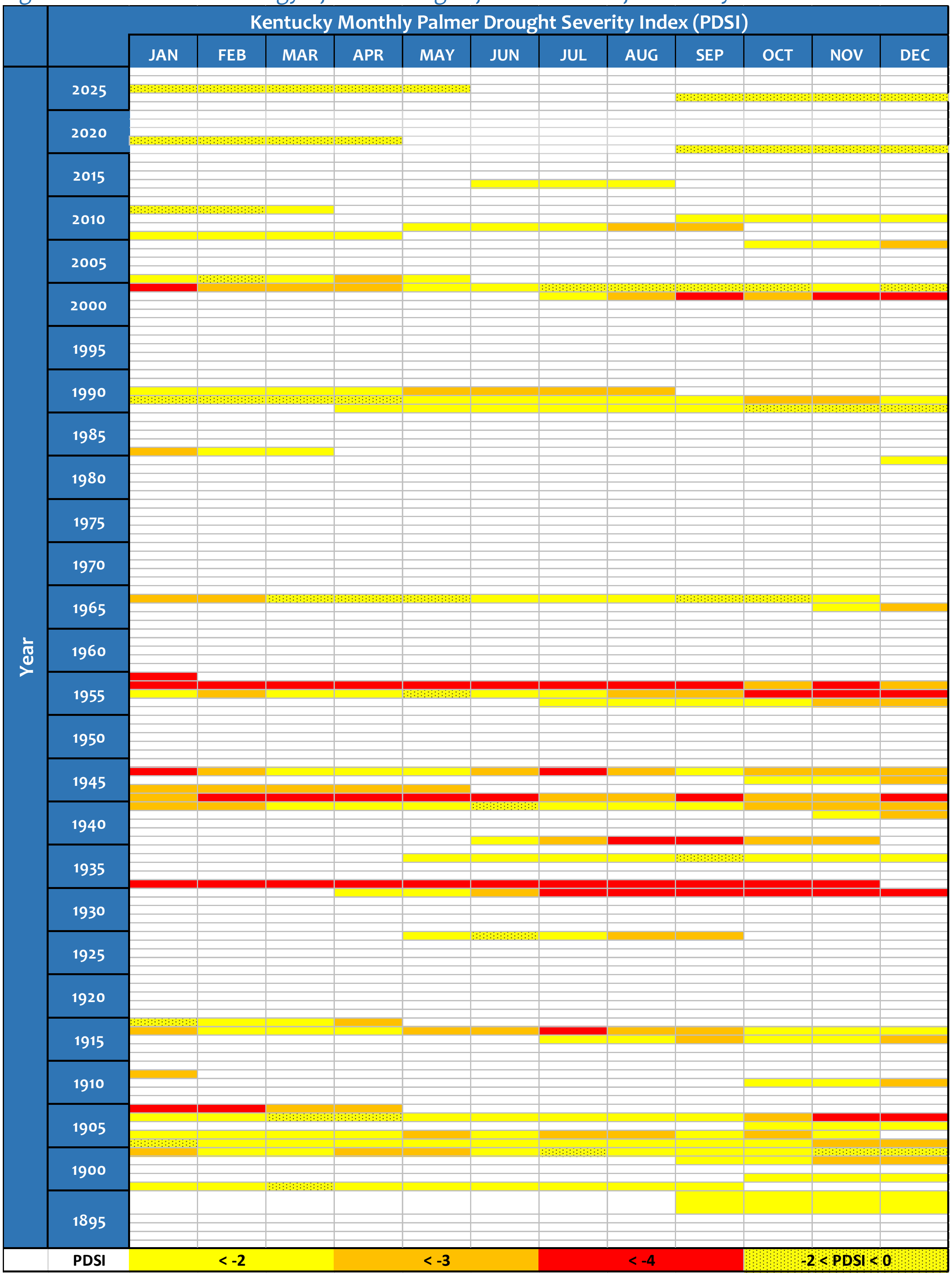
Source: National Oceanic and Atmospheric Association (NOAA)

The PDSI denotes drought severity on a scale of -8 to +8, with any value greater (less) than +4 considered extremely wet and -4 extremely dry.

For purposes of this assessment, moderate drought is reached when at least three consecutive months fall below a PDSI value of -2.0 (Mahmoud, 2014). Drought is considered to persist until the PDSI is once again in a normal (at least zero) range. Severe drought is indicated when PDSI reaches -3.0, and extreme drought is indicated when PDSI fall below -4.0.

As seen in Figure 2 for the period 1905 through the 1950s severe and extreme drought were consistent in recurring every five to ten years. Beginning in the mid-1960s droughts have lessened in frequency and intensity when compared to decades ending in the 1950s. Droughts from the 1930s through the 1950s remain benchmarks for extreme drought for purposes of planning for water resources projects. On a statewide basis, the most notable drought since the 1950s occurred from 1999 through 2001.

Figure 2. Historic chronology of PDSI drought for the state of Kentucky



Risk Management Agency Cause of Loss (COL)

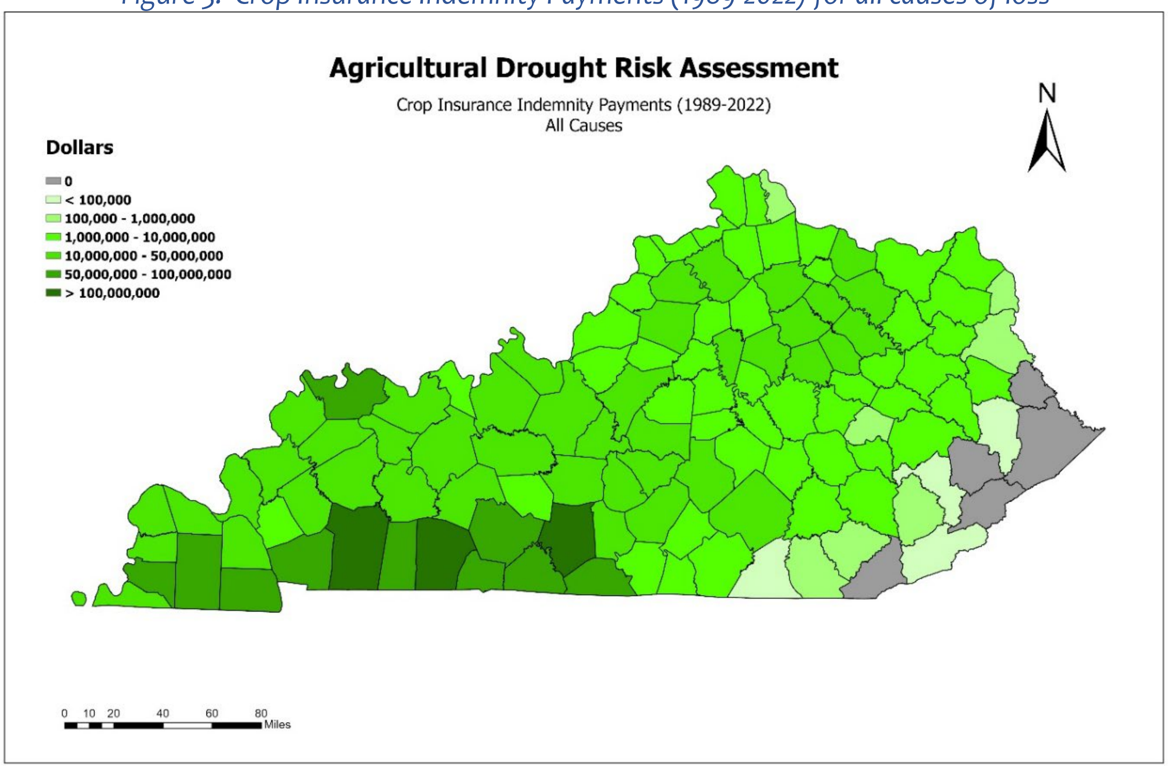
Table 3. Total crop indemnity payments and associated COL

CAUSE OF LOSS ($) - ALL CROPS							
YEAR	DROUGHT	WET	COLD	BIOLOGICAL	PRICE	ALL OTHER CAUSES	TOTAL
	Indemnity Paid ($)						
1989	192,147	3,538,908	17,179	111,255	0	279,776	4,139,265
1990	2,710,968	1,256,732	153,808	100,306	0	214,550	4,436,364
1991	3,164,155	2,084,337	25,872	500,633	0	1,357,143	7,132,140
1992	35,258	1,999,794	90,587	251,358	0	361,086	2,738,083
1993	1,956,356	592,680	37,234	329,472	579,399	185,703	3,680,844
1994	697,902	269,572	26,483	77,939	0	650,224	1,722,120
1995	2,382,551	3,423,593	9,507	822,981	0	471,494	7,110,126
1996	1,177,478	2,867,025	628,689	1,816,126	0	1,049,009	7,538,327
1997	7,740,111	4,330,427	2,460,433	605,070	19,303	329,192	15,484,536
1998	14,700,624	9,808,797	464,337	728,319	291,919	622,888	26,616,884
1999	43,487,995	1,408,098	302,728	1,069,776	6,106,770	1,014,844	53,390,211
2000	7,742,607	3,382,448	959,633	1,035,620	3,976,995	4,011,262	21,108,565
2001	1,531,185	4,117,413	231,419	387,942	1,666,138	1,066,908	9,001,005
2002	22,224,557	5,402,778	184,469	1,203,061	871,648	601,167	30,487,680
2003	447,566	17,270,711	343,069	445,725	33,260	2,158,052	20,698,383
2004	531,529	20,472,975	41,756	934,933	1,139,026	1,086,720	24,206,939
2005	12,493,552	5,026,211	121,406	1,187,035	261,140	835,203	19,924,547
2006	822,297	9,323,613	795,039	831,173	59,021	2,202,598	14,033,741
2007	68,745,873	4,086,497	9,355,691	454,185	27,050,172	1,225,984	110,918,402
2008	62,766,301	7,173,608	420,488	485,710	40,750,412	2,698,259	114,294,778
2009	310,624	56,139,162	774,455	2,786,194	10,155,026	2,580,174	72,745,635
2010	79,653,784	49,312,874	48,286	2,152,299	2,995,986	4,171,384	138,334,613
2011	48,117,307	46,038,605	147,270	1,009,806	2,238,014	2,651,125	100,202,127
2012	455,753,821	2,415,612	7,488,866	836,521	20,010,696	4,222,162	490,727,678
2013	598,591	54,202,746	176,229	530,434	2,365,082	4,507,070	62,380,152
2014	50,883,390	31,198,929	7,459,673	8,200,243	27,147,306	16,246,799	141,136,340
2015	2,731,120	89,422,889	448,006	589,797	1,154,675	5,939,172	100,285,659
2016	6,607,985	107,768,024	607	1,909,811	3,856,131	3,152,215	123,294,773
2017	9,393,871	73,058,765	956,075	2,110,297	1,986,667	4,857,575	92,363,250
2018	7,290,584	94,711,454	1,030,553	2,442,819	4,559,239	2,564,208	112,598,856
2019	38,492,805	91,383,315	649,445	1,692,212	8,597,968	1,321,569	142,137,312
2020	7,029,171	77,785,465	5,695,676	1,106,083	8,702,139	2,763,270	103,081,803
2021	11,032,417	48,623,503	11,540	3,356,046	10,311,875	1,700,887	75,036,267
2022	121,517,226	25,890,020	449,506	1,294,355	16,528,541	2,065,119	167,744,767
TOTAL	**1,094,963,707**	**955,787,580**	**42,006,013**	**43,395,537**	**203,414,547**	**81,164,788**	**2,420,732,173**

Cause of loss data is available for the years 1948 to present. However, the percent of cropped acres insured remained relatively minor until the mid to late 1980s. Total indemnity payments from 1948 to 2022 equaled $2,514,163,329 and $2,420,732,173 from 1989 to 2022. Over 96 percent of crop loss indemnity payments have occurred since 1989 in Kentucky.

Cause of loss data attributes a specific cause to a claim of damage to an insured crop and is comprised of 30 different types of causes. For this assessment, six categories were created (Table 3.) to combine related COL items for analysis: Drought, Wet, Cold, Biological Damage, Price/Yield Protection and Other. As shown in Table 3 drought (drought, heat and hot wind) account for almost 1.1 billion of the 2.4 billion dollars in indemnity payments since 1989, with 53 percent attributed to drought in 2012 and 2022 alone. Figures 3 and 4 present a county assessment of indemnity payments. As would be expected, a majority of crop indemnity payments occur in grain and tobacco producing areas of western and central Kentucky.

Figure 3. Crop Insurance Indemnity Payments (1989-2022) for all causes of loss



Source: USDA Risk Management Agency

Figure 4. County assessment of the percent of crop indemnity attributed to drought

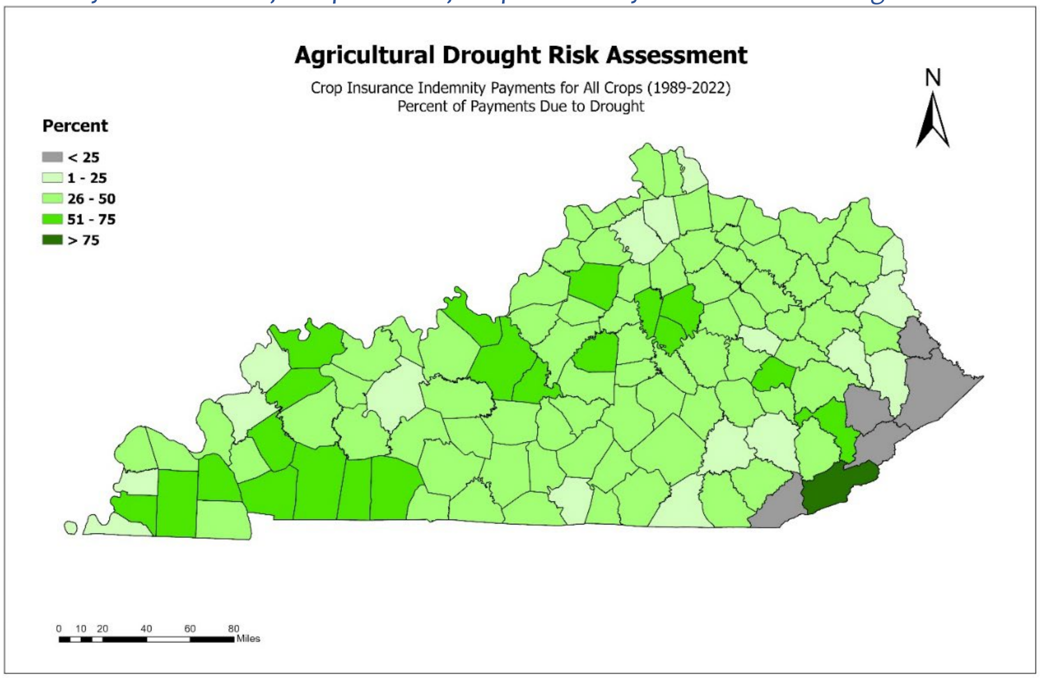


Figure 5. Crop Insurance Indemnity Payments (1989-2022) for Corn, Soybean, Tobacco and Wheat

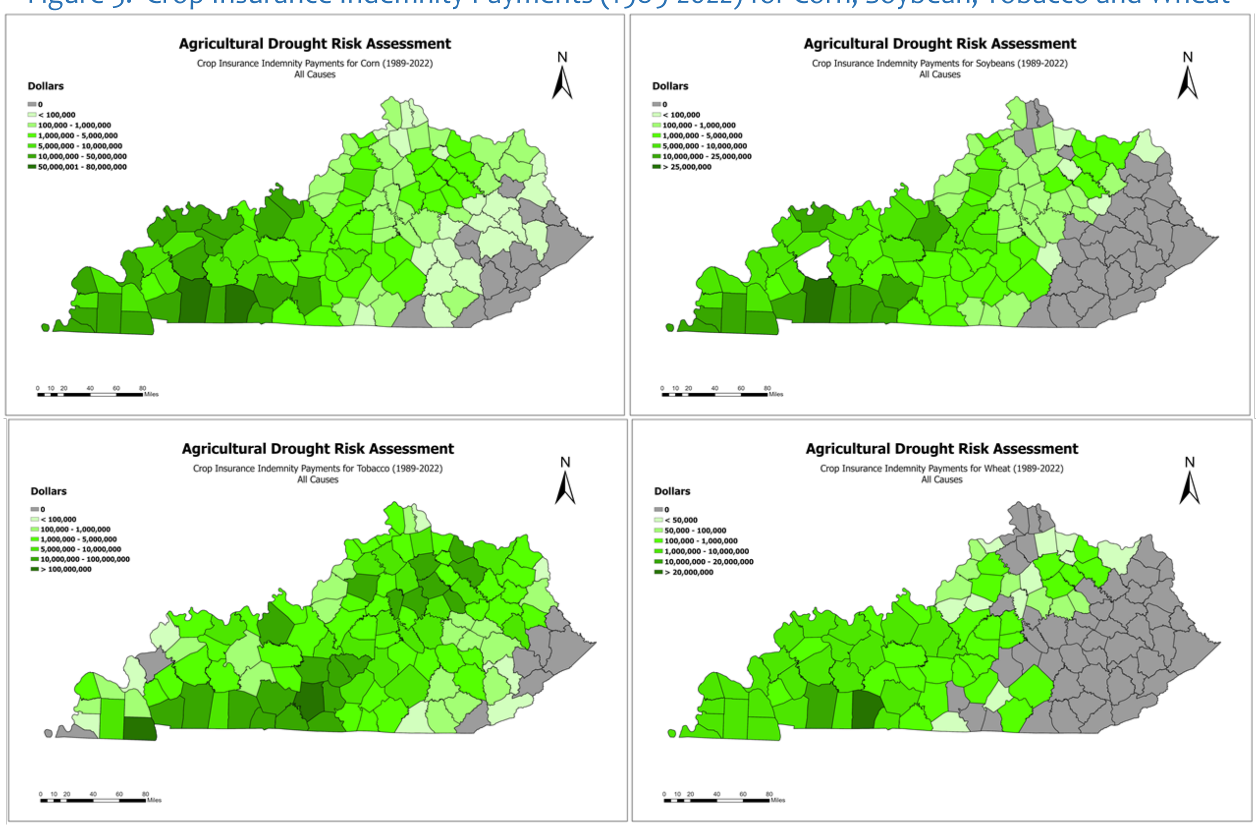
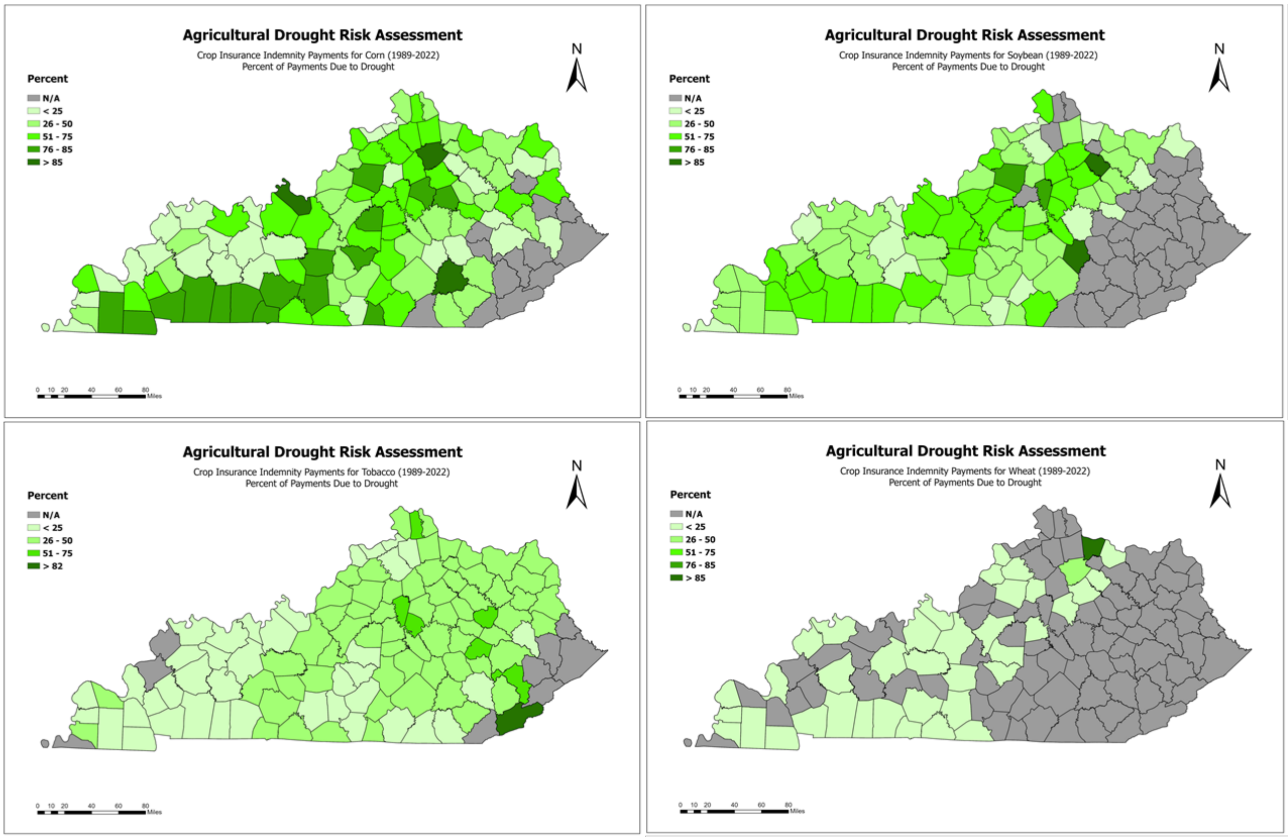


Figure 6. Percent of Crop Insurance Indemnity Payments (1989-2022) Attributed to Drought for Corn, Soybean, Tobacco and Wheat



Corn leads all crops in drought susceptibility followed by tobacco and soybeans. Drought is rarely cited as a COL for wheat, which tends much more toward problems caused from freezing or excess moisture.

PDSI Drought Analysis

Data for PDSI (1895-2015) for each of four climatic divisions in Kentucky was analyzed to determine each occurrence of at least moderate drought (three consecutive months where PDSI < -2.0). The number of occurrences were recorded and the number of months < -2.0, < -3.0 and < -4.0 were counted, and noted whether they occurred in May – November (net water consumption months) and December – April (net recharge months). These were divided by the total number of months < -2.0 determine PDSI severity for each season (consumption or recharge). Results are presented in tables 4 and 5.

Table 4. PDSI Analysis of Drought Incidence in Kentucky for all years where moderate drought advanced to severe or extreme

CLIMATE DIVISION	1895	1897	1899-1902	1903-1905	1908	1913-1915	1922	1925	1930-1931	1934	1936	1939-1942	1943-1945	1952-1955	1963-1964	1980-1981	1986-1988	1999-2001	2005	2007	2008	2010	2012
1																							
All Months		0.75	0.67	0.43	0.50	0.78		0.38	0.85		0.58	0.65		0.79	0.56		0.31	0.25		0.50		0.50	0.80
May-Nov		0.50	0.85	0.17	0.50	0.77		0.67	0.86		0.86	0.53		0.79	0.33		0.40	0.33		0.50		0.33	1.00
Dec-Apr		1.00	0.20	0.63	0.50	0.80		0.00	0.83		0.25	0.84		0.73	1.00		0.00	0.25		0.00		1.00	0.00
2																							
All Months		0.50	0.45	0.70		0.61		0.50	0.85	0.17	0.83	0.75	0.63	0.77	0.60	0.25	0.13	0.50		0.20			
May-Nov		0.66	0.47	0.40		0.55		0.50	0.86	0.00	0.83	0.65	0.50	0.68	0.00	0.00	0.20	0.46		0.20			
Dec-Apr		1.00	0.42	1.00		0.71		0.00	0.83	1.00	0.00	0.86	0.75	0.92	1.00	0.25	0.00	0.50		0.00			
3																							
All Months	0.778		0.70		0.60	0.11	0.50		0.95	0.60	0.86	0.70	0.93	0.61	0.25		0.52	0.63	0.71	0.25	0.16		
May-Nov	0.75		0.75		0.33	0.13	0.33		0.93	0.43	0.83	0.82	0.89	0.63	0.00		0.39	0.64	0.33	0.25	0.25		
Dec-Apr	0.8		0.80		1.00	0.00	1.00		1.00	1.00	1.00	0.62	1.00	0.58	0.60		0.80	0.71	1.00	0.00	0.00		
4																							
All Months	0.17		0.41	0.37		0.20		0.33	0.87		0.83	0.63	0.20	0.74		0.14	0.50	0.61	0.57	0.56			
May-Nov	0.50		0.38	0.22		0.20		0.33	0.90		0.83	0.54	0.17	0.69		0.00	0.58	0.55	0.33	0.45			
Dec-Apr	0.00		0.44	0.50		0.17		0.00	1.00		0.00	0.73	0.25	0.83		0.25	0.33	0.71	0.75	0.60			

CLIMATE DIVISION	MINIMUM PDSI FOR THE DROUGHT PERIOD																						
1	-2.03	**-3.19**	**-4.05**	**3.63**	**-3.26**	**-5.35**	-1.28	**-3.81**	**-6.17**	-2.57	**-5.23**	**-5.61**	**-4.62**	**-5.51**	**-4.75**	-2.83	**-3.34**	**-3.19**	-1.93	**-3.66**	-2.12	**-3.60**	**-4.40**
2	-2.46	**-3.08**	**-4.12**	**4.12**	-2.85	**-4.28**	-1.38	**-3.16**	**-6.51**	**-3.04**	**-4.01**	**-5.03**	**-3.97**	**-5.47**	**-3.65**	**-3.22**	**-3.35**	**-4.25**	-2.55	**-3.24**	-2.50	-1.43	-2.38
3	**-4.08**	-2.25	**-5.19**		**-4.41**	**-3.43**	**-3.31**	-2.27	**-7.51**	**-4.35**	**-4.31**	**-4.78**	**-4.93**	**-5.39**	**-3.50**	-2.48	**-4.13**	**-5.39**	**-3.80**	**-3.46**	**-3.01**	-2.52	-2.28
4	**-3**	-2.16	**-3.68**	**-3.75**	-2.3	**-3.17**	-1.79	**-3.48**	**-6.47**	-2.72	**-3.53**	**-4.86**	**-3.28**	**-4.89**	-2.55	**-3.49**	**-4.04**	**-4.27**	**-3.57**	**-4.45**		-0.54	-1.99

In some years and climatic divisions the more intense PDSI values occur in the consumption months (1899-1902, 1925, 1936, 1988, 2007, 2012) and most of the rest in the recharge months, with 1930-1931 equally severe in both seasons (Table 4.). This is not unexpected since the PDSI is a slow developing, longer-term index that is not well suited to detect short-term droughts. It is worth noting that the years 1936, 1988, 2007 and 2012 were rapidly developing, intense droughts that did tremendous damage to agriculture with lesser impacts to pubic water supplies. The data supports the observations that the years between 1930 and the late 1950s were generally drought-prone and subject to multi-year droughts and tending to persist much longer than droughts that are more recent in Kentucky.

Table 5 summarizes the data by categorizing and summing years that reach moderate and severe PDSI thresholds as well as the number of regional (less than 4 climatic divisions reach a severe drought level) and statewide droughts (all climatic divisions reach at least a severe drought level. The data supports the observation that drought incidence and recurrence is very similar between all four climatic divisions.

Table 5. Recurrence intervals for moderate, severe, regional and statewide droughts

CLIMATE DIVISION	Moderate Drought Criteria Met	Recurrence Interval, years	Severe Drought Criteria Met	Recurrence Interval, years	Regional Droughts	Recurrence Interval, years	Statewide Droughts	Recurrence Interval
	Number of Droughts							
1	21	6.1	17	7.6	6	21.5	11	11.7
2	24	5.4	16	8.1	5	25.8	11	11.7
3	20	6.5	18	7.2	7	18.4	11	11.7
4	21	6.1	16	8.1	5	25.8	11	11.7
STATEWIDE	28	4.6	23	5.6	12	10.8	11	11.7

Based on table 5 there have been 28 moderate droughts since 1895 with 23 progressing to at least severe drought. There have been 12 regional droughts and 11 statewide droughts. On average Kentucky has experienced a severe drought at least once every 5-6 years. Severe regional droughts are occurring in some area of Kentucky about once every 10 years, and statewide droughts have recurred on an 11-year interval.

Figure 2 and Table 5 show that most droughts that have reached the moderate threshold (28) advanced to at least severe drought (23). Thus, the PDSI has some utility in drought monitoring as a longer-term signal that hydrologic drought may be developing.

Table 6. Recurrence Intervals and Percent Exceedance of 3-month PDSI

Recurrence Interval, years	3- month PDSI			
	Climate Division 1	Climate Division 2	Climate Division 3	Climate Division 4
60	-5.4	-5.4	-6	5.5
40	-5.2	-5	-5.2	-4.5
20	-4.8	-4.1	-4.8	-4.2
10	-4	-3.8	-4.2	-3.6
5	-3.2	-2.8	-3.3	-2.6
2	-1.7	-1.4	-1.7	-1.4
PDSI	**% CHANCE LESS THAN PDSI**			
-6	0.78	1.1	1.75	1.2
-5	4	3.1	4.1	2.5
-4	9.6	7	11.2	7.8
-3	23.5	17.5	24	16.3
-2	38.3	38.4	39.4	38

Finally, monthly PDSI values were evaluated to calculate a three-month running average, the length of a "typical" irrigation season (Table 6.). Recurrence intervals and percent chances for each PDSI threshold were calculated from a Weibull plotting position. Based on this data, on average Kentucky experiences moderate to slightly severe drought about every five years; moderate to somewhat extreme every 10 years, and extreme drought at least every 20 years. The data also suggest there is a 17-24 percent chance of a severe drought and a 7-11 percent chance of extreme drought each year, respectively.

Crop Loss Analysis

Return intervals and percent chances of drought as a percent of total indemnity payments were calculated using a Weibull plotting position on the percent of drought COL versus total payments each year since 1948. Results show that drought has been 90 percent or more of the total indemnity payments on a 15-year recurrence interval, or a 7 percent chance in any year. Drought is at least 50 percent of all indemnity payments at a recurrence interval of 3 years, or about 33 percent chance each year.

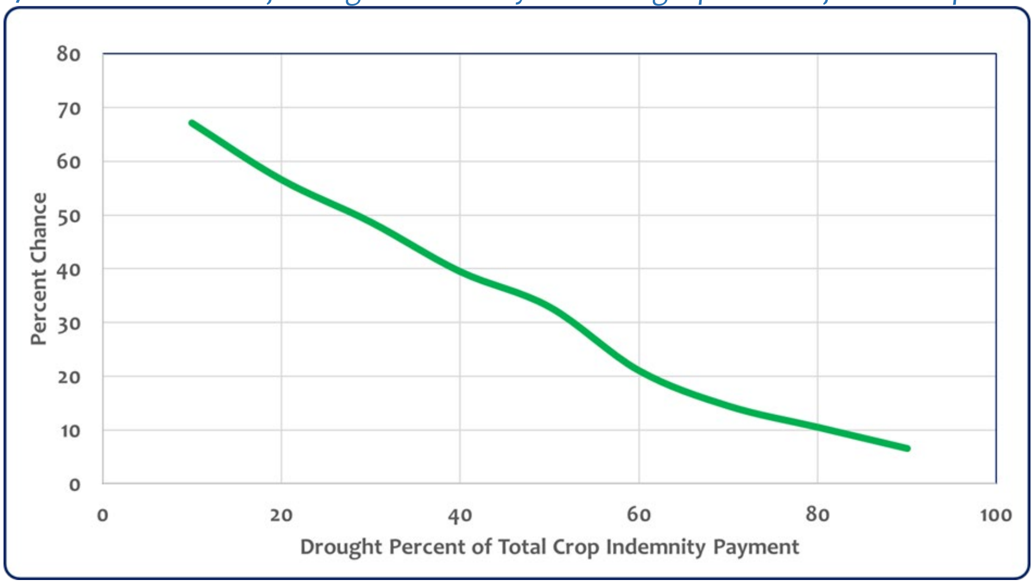
Table 7. Return Intervals and percent chance of occurrence of drought as a COL

% COL Attributed to Drought[1]	Return Interval	Percent Chance Less Than % COL
%	years	years
90	15.2	6.6
80	9.5	10.5
70	6.9	14.5
60	4.8	21.1
50	3.0	32.9
40	2.5	39.5
30	2.1	48.7
20	1.8	56.6
10	1.5	67.1

[1]Cause of Loss (COL) as a percent of total indemnity payments

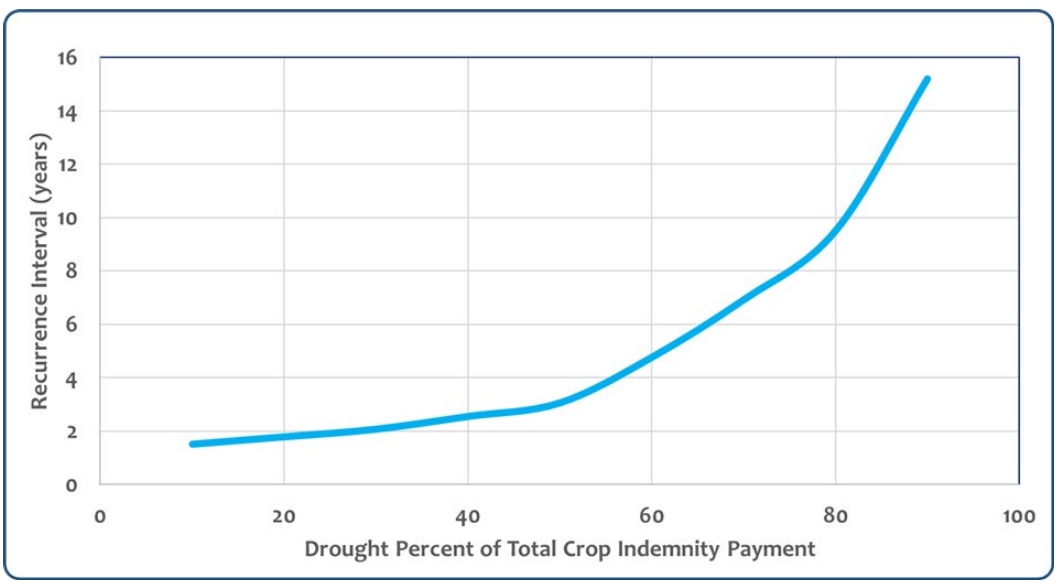
Combining the results from tables 6 and 7 the following relationships may be approximated: when drought makes up 90 percent or more of crop indemnity cause of loss, the three-month PDSI had reached at least a minimum of -4.2. Similarly, for 80 percent drought PDSI had reached a -3.9, for 70 percent drought -3.4 and 50 percent drought when PDSI had reached -2.0. This may be of some use in predicting what level of crop damage each year might be expected from drought with the knowledge that a majority of droughts progress to severe or worse once the threshold for moderate drought is reached.

Figure 7. Percent chance of drought indemnity exceeding a percent of total crop indemnity



Figures 7 and 8 present generalized relationships between COL attributed to drought and the PDSI from Tables 6 and 7. For example, figure 7 shows there is about a 40 percent chance that annual crop indemnity payments will attribute at least 40 percent of the causes of loss to drought. Similar visual relationships are presented in Figure 8 for recurrence intervals for percent drought as a cause of loss. From Figure 8 a 40 percent COL due to drought has a return interval of about 2.5 years. The corresponding PDSI from Table 6 with a similar return interval is approximately -2 and suggests that a significant amount of drought losses have occurred when PDSI indicated only moderate drought.

Figure 8. Recurrence intervals for drought indemnity exceeding a percent of total crop indemnity



Drought Risk Assessment Results

Methods

Public Water Supply Scoring

Source Score- Created by taking a system's raw water source(s) and assigning a score (from 1 to 5 with 5 being the least vulnerable) based on how drought vulnerable the source(s) are. Streamflow variabilities, lake characteristics, historical documents, and the system's demand compared to the size of the source, were taken into consideration. Sources that have experienced issues in the past or have the potential to experience a shortage in a moderate to significant drought were given a severe- to high-risk score (1 or 2). Sources that have the potential to experience a shortage in a significant drought were given a moderate risk score (3). Sources that were unlikely to experience a shortage during a severe drought were given a low-risk score (4). Sources that would not experience a shortage during a significant drought were give a minimal-risk score (5). Minimal-risk sources include the Ohio River, USACE Lakes and the Mississippi Embayment Aquifer. Systems that purchase water were scored based upon the score of the system(s) the water is purchased from.

Management Score- Created by rating a systems ability to manage water supplies during a drought. This includes interconnections with other systems and the amount of available plant capacity. The system's past management during past droughts is taking into consideration. Systems that have a source with a score of 5 were not scored on management.

Supply Score-Created by taking the average of the source and management score.

Water Loss- Percent water loss is the percent of treated water produced by a system that is unaccounted for. This can be caused by several things including leakage from pipes, slow running meters, and theft. For this analysis, it is being assumed that a large portion of the unaccounted for water is due to leakage from pipes. This was determined using data from the Kentucky Infrastructure Authority's Water Resource Information System (WRIS).

Distribution Lines 3 Inches or Less- Calculated using the miles of lines that are 3 inches or less divided by the total miles of lines in a system.

Infrastructure Score- Created by taking the average of the Leakage Loss and Distribution Line 3 Inches or less scores.

Public Water System Hazard- Is calculated by averaging the Supply Score and the Infrastructure Score. The score is weighted for the Supply Score at a ratio of 2:1.

County Hazard Level for Public Water Systems- Scores for all systems that are in a given county were weighted based upon the number of people that system serves in that county and then averaged.

*It should be noted that with all water system maps, systems that purchase 100% of their water from another system were merged with that system and assigned scores of the selling system.

Soil Hazard Mapping

The soil hazard score was created by assigning every soil in the state with a hazard score. The soils were defined using the 87 different NRCS Soil Surveys that encompass the state. While many soils share the same name from survey to survey, many parameters can vary slightly which results in 2,900 unique soils for the state.

To determine the drought hazard for each soil, 3 criteria were used: Infiltration, Water Movement, and Water Supply. Each criterion then consisted of associated soil properties that are rated in each soil survey: Infiltration (Representative Average Slope, Hydrologic Soil Group, and Soil Surface Sealing), Water Movement (Saturated Hydraulic Conductivity-Ksat), and Water Supply (Available Water Capacity, Depth to Water Table, and Depth to Restrictive Layer). Each of the properties were scored on a scale of 0 to 5 with 0 being the most drought vulnerable. The exception was Depth to Water Table which was scored 4-5 as a way to boost the scores of soils with high water tables without punishing other soils since all other scoring is done assuming a water table below 80".

The average score of the soil properties was used to calculate the score for each of the three criteria. The scores of the criteria were then averaged to calculate the drought hazard score for each soil. The scales for the soil properties were determined using NRCS rankings:

Table 8. Seven soil moisture variables used to develop a soil drought hazard assessment

Slope:	Score		Saturated Hydraulic Conductivity (Ksat)	Score
0-3%	5		Very High	5
3-8%	4		High	4
8-16%	3		Moderately High	3
16-30%	2		Moderately Low	2
30-60%	1		Low	1
>60%	0		Very Low	0
Hydrologic Soil Group:	**Score**		**Available Water Supply in Profile**	**Score**
A or A/D	5		Very High	5
B or B/D	3.33		High	3.75
C or C/D	1.67		Moderate	2.5
D	0		Low	1.25
			Very Low	0

Soil Surface Sealing	Score	Depth to Restrictive Layer	Score
Low	5	>80"	5
Moderate	2.5	60-80"	3.75
High	0	40-60"	2.5
		20-40"	1.25
		<20"	0
Depth to Water Table	**Score**		
<20"	5		
20-40"	4.5		
40-60"	4.25		
60-80"	4		
>80"	n/a		

Hazard Level for All Soils Used for Crops

The map was created in ArcGIS Pro by laying the Soil Drought Hazard map on top of the 2019 National Land Cover Data (NLCD) map and then clipping the NLCD layer to leave only the areas designated as "crop", leaving only the soils that overlay the crop areas.

Hazard Level for All Soils Used for Pasture/Hay

The map was created in ArcGIS Pro by laying the Soil Drought Hazard map on top of the 2019 National Land Cover Data (NLCD) map and then clipping the NLCD layer to leave only the area designated as "Pasture/Hay", leaving only the soils that overlay these areas.

Public Water System Risk Assessment

Maps in the water system risk assessment have been developed to denote water service areas using shaded areas. These service areas were determined by constructing polygons from water line layers in ArcGIS Pro. Areas not served by a public system area are labeled as N/A.

Water Supply Source Assessment

The majority of water systems in the state rely on sources that have a minimal to low drought vulnerability but system with sources that have moderate to extreme vulnerabilities do exist (Figure 9). Looking at the breakdown by watershed (Table 9) the highest number of system with moderate to extreme source vulnerability are located in the Big Sandy, Licking, Upper Cumberland, Upper Green, and Upper Kentucky Watersheds. Unfortunately, these watersheds are located in headwater areas with few reliable sources. The mountainous topography of the area also presents challenges in running water lines more reliable water sources. Water sources in these areas include small lakes, abandoned mine shafts, and rivers with relatively small watersheds, all of which are more vulnerable to drought. The Licking, Upper Green, and Upper Cumberland also have a large number of systems with minimal to low source vulnerability. These are typically associated with larger drainage basins and on or below US Army Corp of Engineers (USACE) projects. These lakes provide a large amount of water storage and minimum releases, insuring reliable water supply during moderate to severe drought.

The Lower Kentucky watershed has a large proportion of low vulnerable sources. This is mainly due to the heavy usage in both the upper and lower watersheds resulting in low-flows during past severe droughts. The Kentucky River provides water to a significant portion of south eastern Kentucky and most of the Bluegrass Region, including Lexington. During normal conditions, and even moderate droughts, the river is a reliable source. Recent severe droughts such as 1988 and 1999 have shown that the Lower Kentucky is vulnerable to water shortage. There 2 USACE projects in the Upper Kentucky, Carr Fork Lake and Buckhorn Lake. These reservoirs are relatively small when compared to projects in the Cumberland, Licking, Big Sandy and Green River watersheds. The result is smaller minimum releases and less reliability during drought. So while it is unlikely that water shortage issues would occur in the Lower Kentucky River during a Severe Drought, a small risk does exist.

The Upper and Lower Green watersheds are home to four large USACE projects (Green River Lake, Nolin River Lake, Barren River Lake, and Rough River Lake) which provide reliable and relatively easy access to most systems in the watershed. There are a few systems in these basins that rely on small, drought vulnerable, lakes.

Further into western Kentucky, the Ohio, Tennessee, and Cumberland rivers, along with the Mississippi Embayment Aquifers provide some of the most abundant and reliable water supplies for water systems in the state. The lack of water line coverage in many areas west of Land Between the Lakes is due to the Mississippi Embayment Aquifers providing not only abundant amounts of water, but also clean water that can be easily pumped and treated by residents. The sparse populations, and easy access to clean water has resulted in areas with no public water system coverage.

In addition to source water reliability. Water systems management was also taken into account factoring in both the source and system management the supply vulnerability, factoring in both the source and system management (Figure 11). The main factor in evaluating this was interconnections to other systems. A system with a drought vulnerable source can improve their situation with reliable interconnection(s) to neighboring systems that rely on less drought vulnerable sources. Available plant capacity was also factored in to account for a system's ability to meet abnormally high demand during hot, dry conditions associated with a drought.

Figure 9. Vulnerability of water sources for Kentucky public water systems

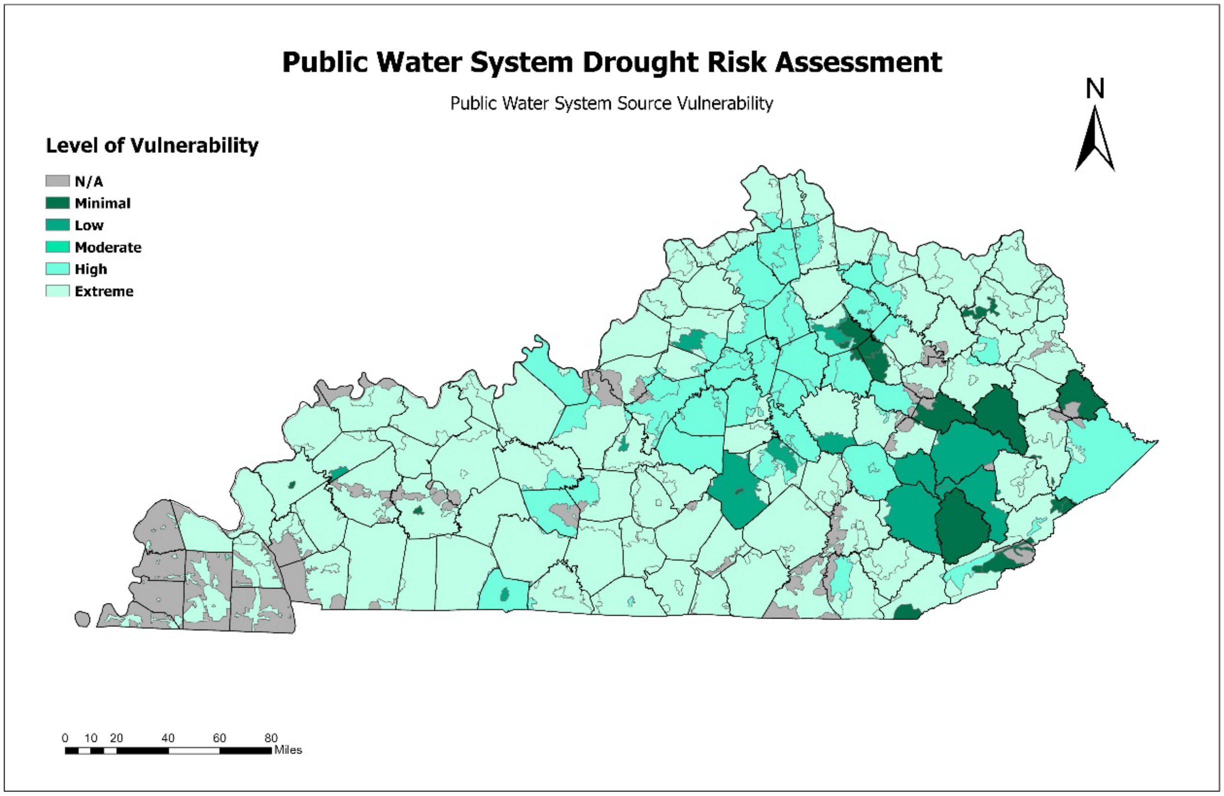


Figure 10. Watersheds of Kentucky

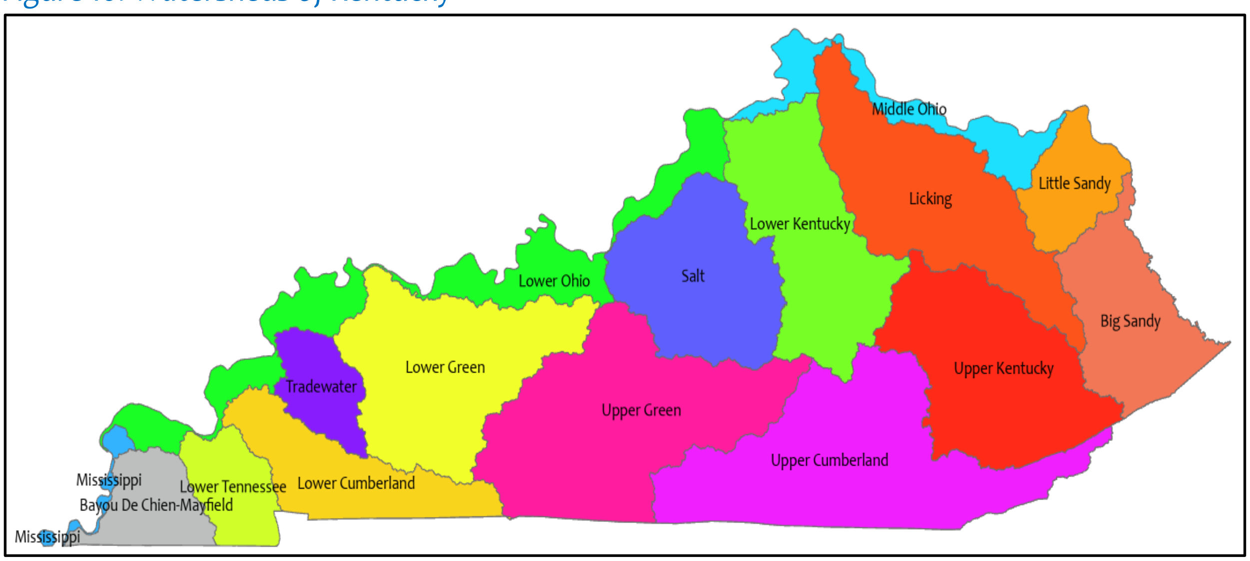
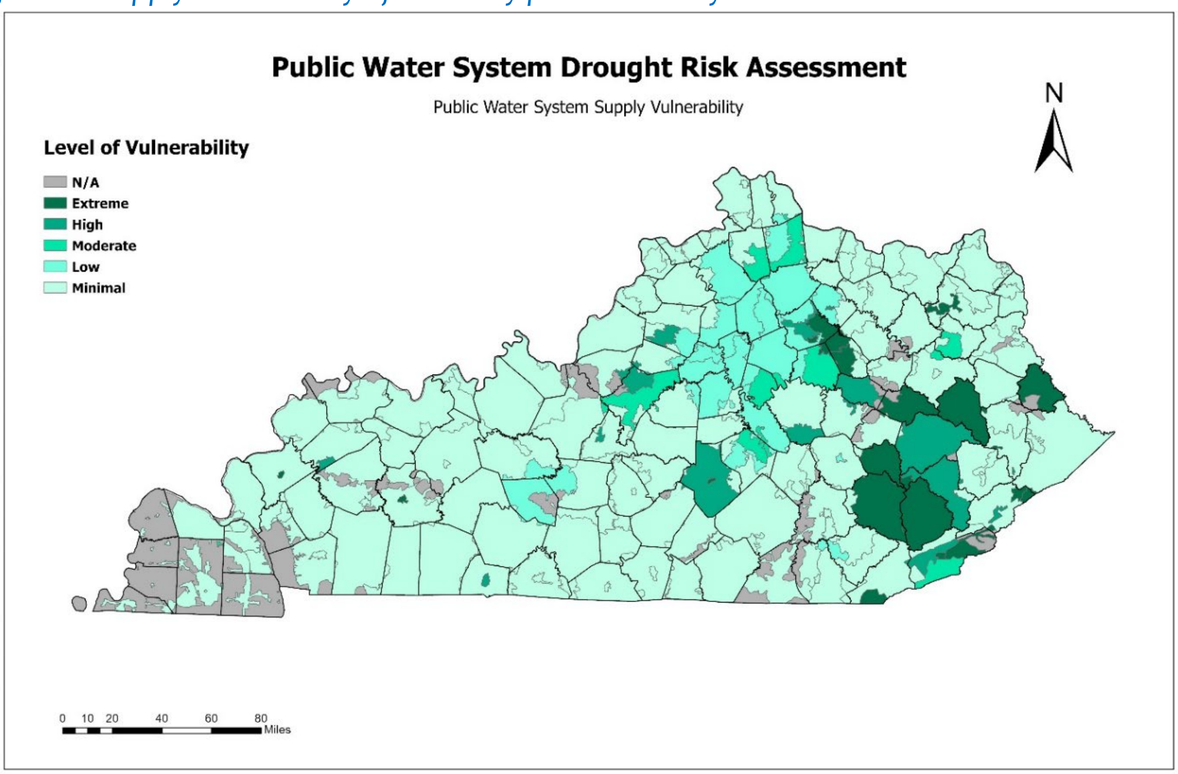


Table 9. Vulnerability of water sources for Kentucky public water systems by Watershed

Watershed	Average Source Vulnerability	Number of Systems in each Category				
		Minimal	Low	Moderate	High	Extreme
Bayou De Chien-Mayfield	5.00	14	0	0	0	0
Big Sandy	3.73	6	1	0	3	1
Licking	3.85	7	8	2	1	2
Little Sandy/Tygarts	4.00	2	1	0	1	0
Lower Cumberland	5.00	10	0	0	0	0
Lower Green	4.76	15	1	0	1	0
Lower Kentucky	3.89	2	12	4	0	0
Lower Ohio	4.79	22	1	0	0	1
Lower Tennessee	4.89	8	1	0	0	0
Middle Ohio	5.00	21	0	0	0	0
Mississippi	5.00	2	0	0	0	0
Salt	3.75	0	3	1	0	0
Tradewater	4.00	1	0	1	0	0
Upper Cumberland	4.12	20	6	1	3	3
Upper Green	4.44	11	2	2	1	0
Upper Kentucky	3.29	3	3	4	3	1

Figure 12. Supply vulnerability of Kentucky public water systems



Water Supply Infrastructure Assessment

The infrastructure of water systems was also taken into account when determining drought risk. The first factor examined was the amount of water loss a system has. Systems with a high water loss are more vulnerable to drought when a portion of the water being withdrawn from the source is lost. Experience has shown that certain systems that experience low availability during drought often are losing more water than the water conservation efforts are saving. This reduces the effectiveness of conservation efforts since those efforts will only impact the percentage of water making it to customers. During a recent non-drought related water shortage in western Kentucky, a system was able to dramatically decrease water loss through an intensive leak detection and repair project.

The percent of water lines 3 inches or less is also used to create the infrastructure score. During drought, when demand for water often spikes a system may have difficulty meeting demands. Customers supplied by smaller lines, many in rural areas, will be impacted more frequently. Systems with a higher percentage of 3 inch, or smaller, lines have a high number of customers that could be impacted during periods of high usage, or limited supply.

Unlike supply vulnerability, the infrastructure vulnerabilities are more widespread across the state. Systems with the highest vulnerabilities are concentrated across the Upper Cumberland watershed and in the northeast. This intermixing is not due to topography or proximity to a reliable source, but management and financial limitations. This can be an issue with any water system in the state, hence the wider distribution. This is also a vulnerability that can be mitigated with proper planning and investment in infrastructure and system maintenance.

It should be noted that a few public water systems do not make their water line information available. Those areas are listed as "N/A" along with areas not served by a public water system.

Figure 13. Percent Unaccounted for water as an indicator of drought vulnerability of a water system

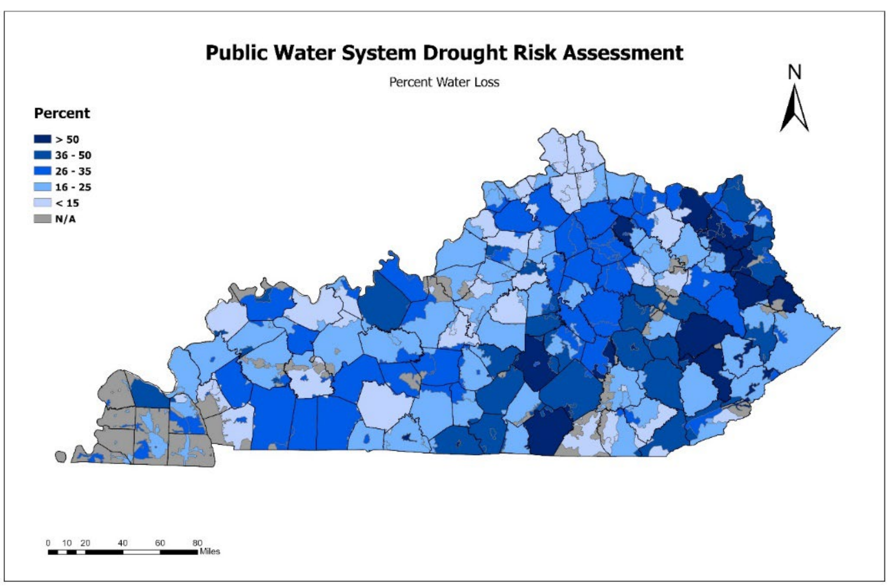


Figure 14. Percent of three inch or less water lines as indicators of potential water distribution problems during drought

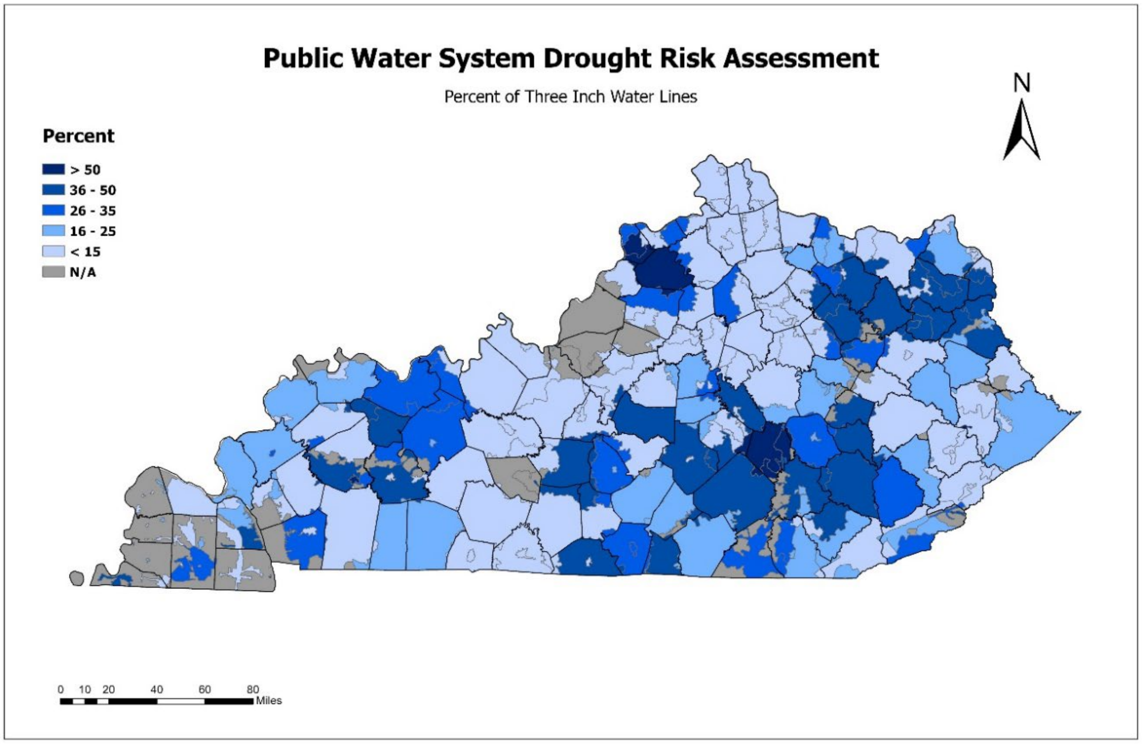
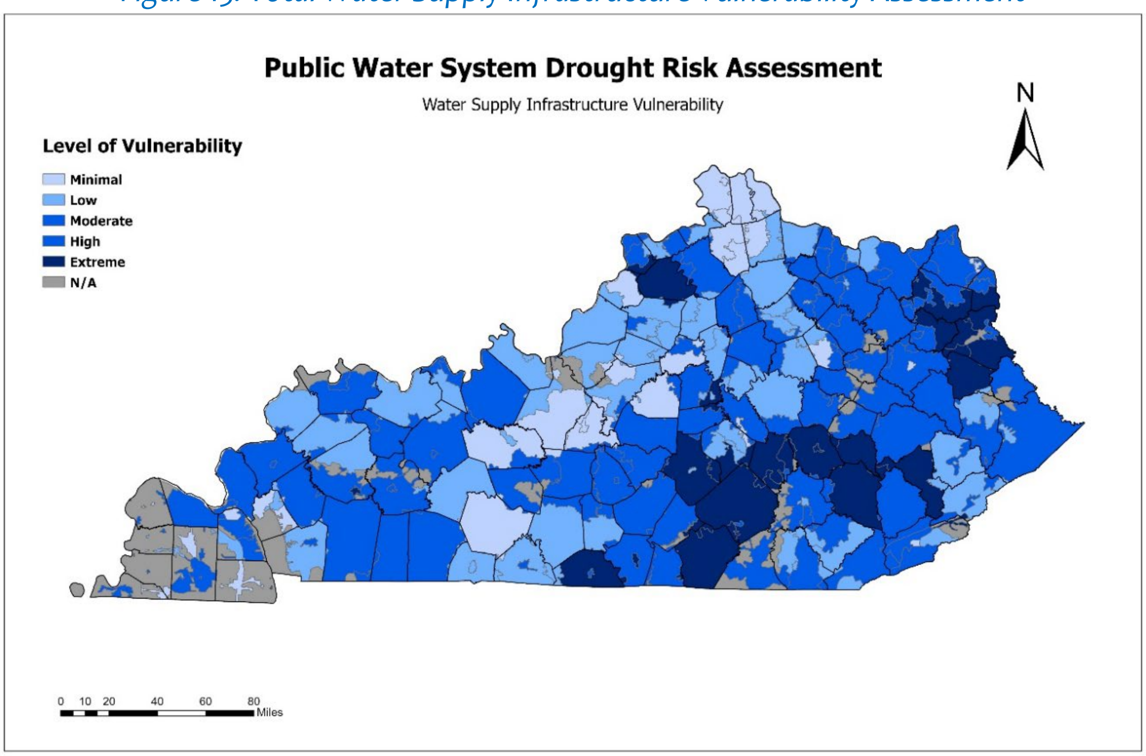


Figure 15. Total Water Supply Infrastructure Vulnerability Assessment



Water Supply Final Assessment – Public Water Supply Drought Hazard

The overall hazard for public water systems was calculated by averaging the Source Water Vulnerability score and the infrastructure vulnerability score. The Source Water Vulnerability Score was weighed 2:1 since the source is ultimately the most important parameter. Much like the Source Water Vulnerability Map, the Public Water System Hazard map shows that much of the state is in the minimal to low hazard categories. The highest concentrations of the high and extreme hazards are located in eastern Kentucky. When looking at the hazard by population, the state's largest population centers have low to minimal drought hazards for their public water systems. Systems in the high to extreme hazard areas not only have drought vulnerable sources, but also infrastructure issues that further stress these systems. The results of this risk assessment should highlight the need for focused investment in areas with high to extreme risk to identify reliable alternative sources or interconnections and in improvements to infrastructure.

According to customer numbers provided by WRIS, approximately 11.4% (481,943 people) of people served by public water systems that have at least a Moderate Drought Hazard. That number drops to 1.8% (76,593 people) when looking at customers served by public water systems in Extreme Drought Hazard. While it is difficult to find direct correlation to drought hazards and public health, who direct correlation is people who are in hospitals or long-term care facilities served by at-risk systems. This is a segment of the population that is already vulnerable and likely the first to be impacted by water loss. An estimated 10.5% of beds (both hospital and long-term care facilities) are served by public water systems that have at least a Moderate Drought Hazard. When looking at just Extreme Drought Hazard systems, still 2.2% of beds are served by these systems.

This drought risk assessment is only taking into account a moderate to severe drought, similar to what the state experienced in 1988 or 1999. A more intense drought, such as what the state experience in 1954 and 1955 would result in widespread water shortages even in system that have a minimal or low hazard.

Figure 16. Overall public water system Hazard

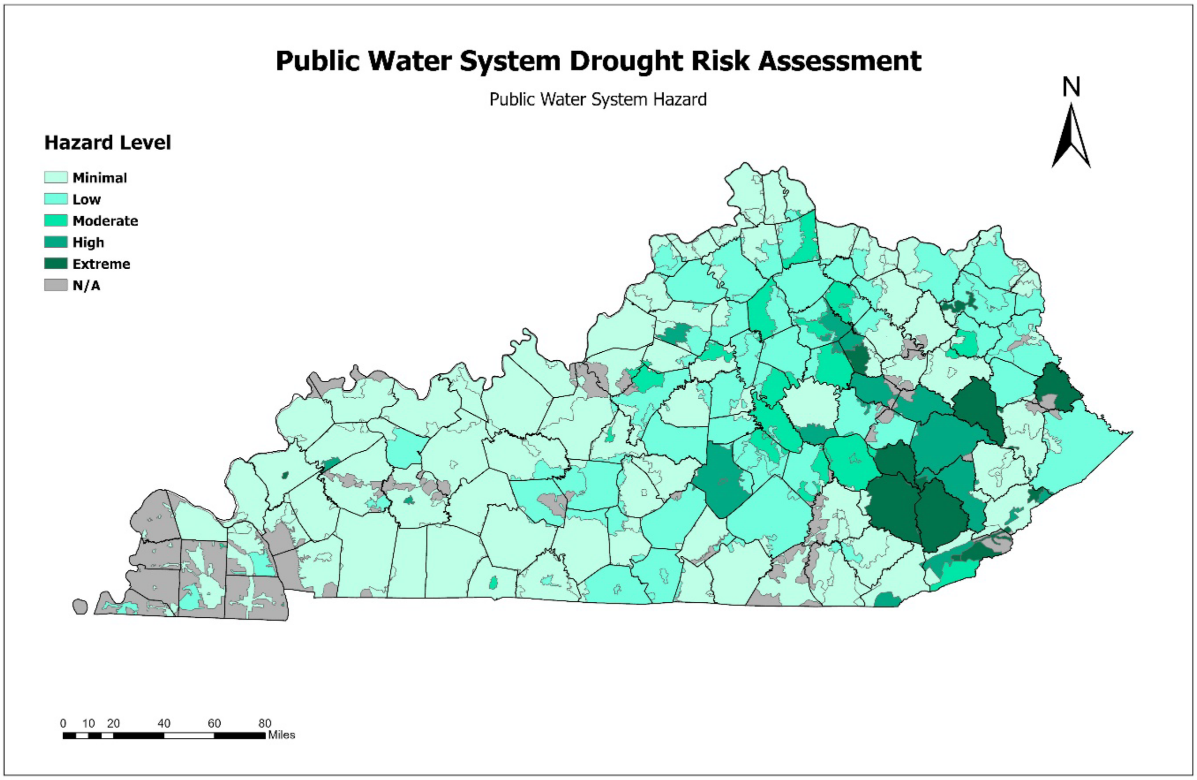


Figure 17. Overall public water system hazard by county

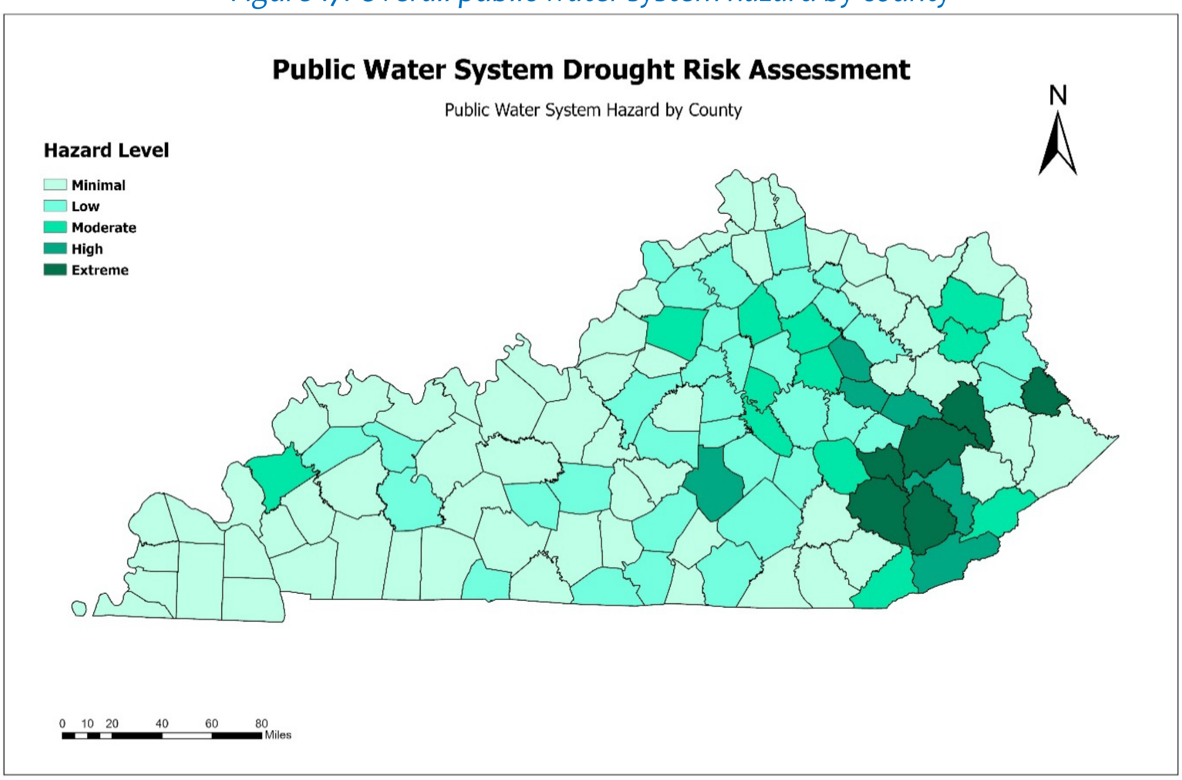


Table 10. Number of Customers located in drought hazard water systems.

Drought Hazard	Customers Served	% of all Customers
All	4,238,075	--
Moderate to Extreme	481,943	11.4%
High to Extreme	216,297	5.1%
Extreme	76,593	1.8%

Figure 18. Water supply risk as number of people served by moderate to extreme drought hazard water systems

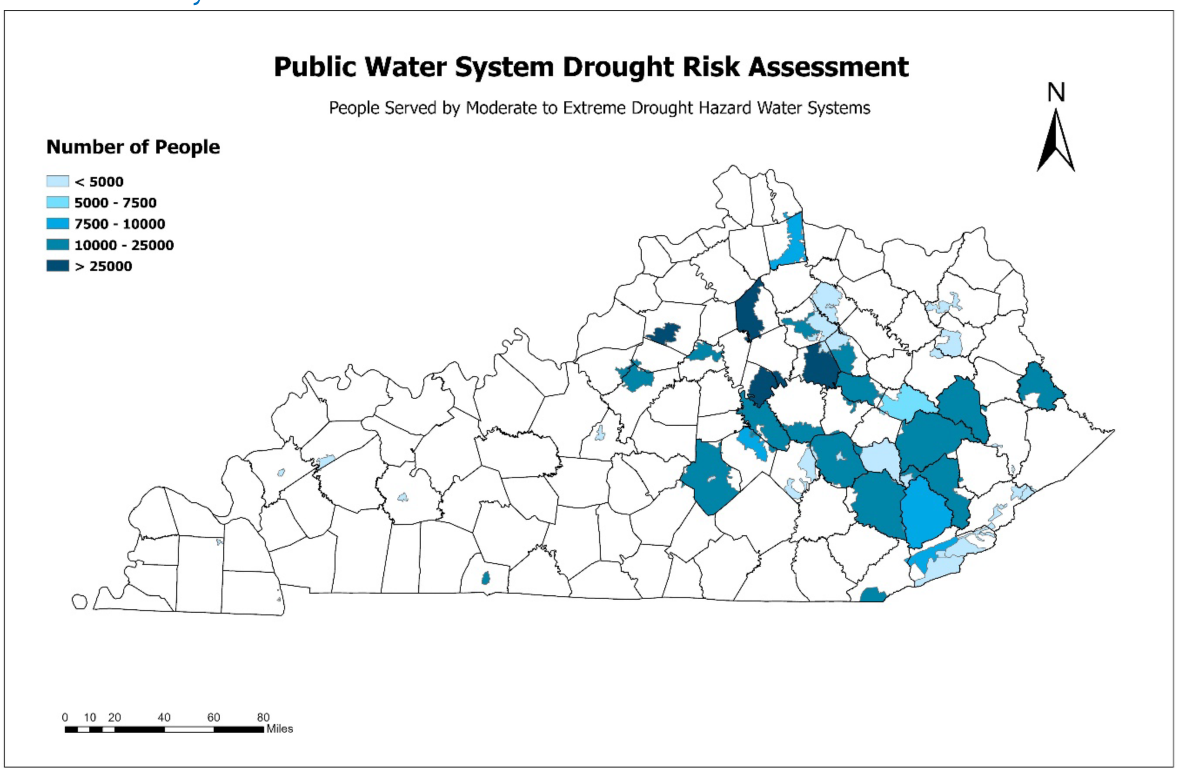


Figure 19. Water supply risk as number of people per county served by moderate to extreme drought hazard water systems

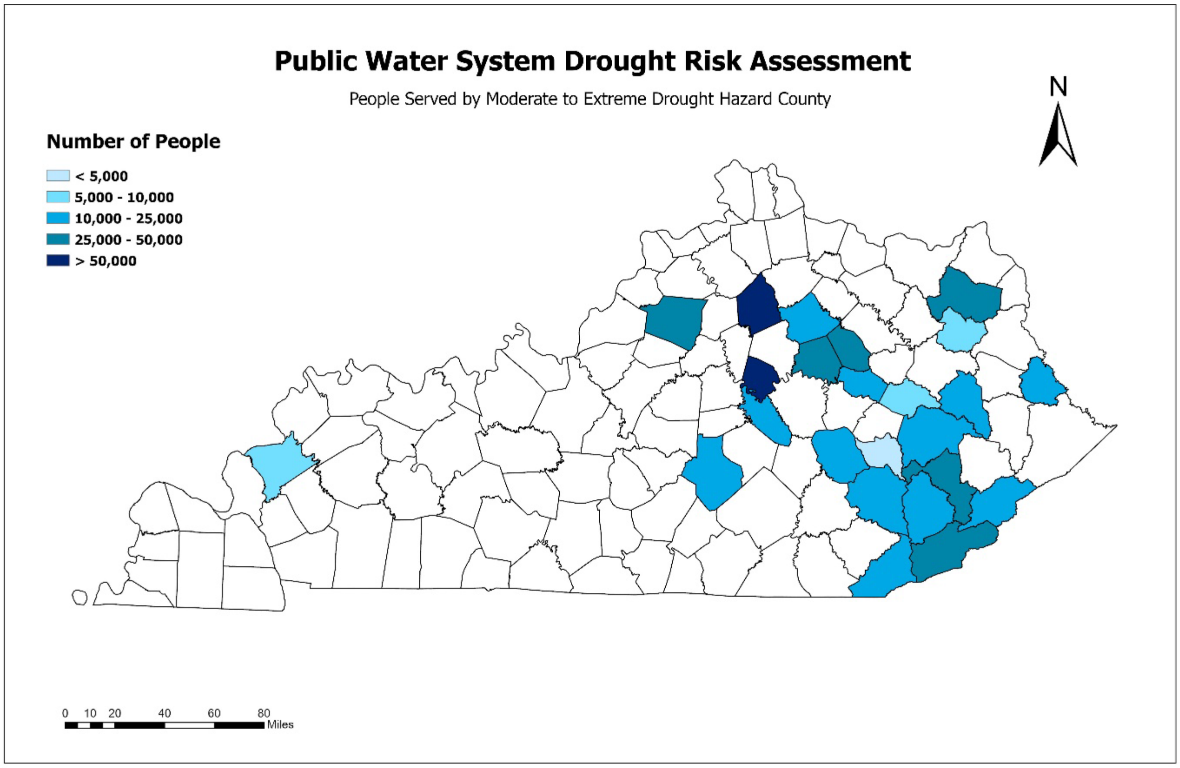


Table 11. Water supply risk as percentage of people per county served by moderate, high or extreme drought hazard water systems.

	Population	Percentage of Served Population				Population	Percentage of Served Population		
County	Served	Moderate	High	Extreme	County	Served	Moderate	High	Extreme
Adair	17,044	0.0	0.3	0.0	Knox	28,836	0.0	0.0	0.0
Allen	19,996	0.0	0.0	0.0	Larue	14,800	27.9	0.0	0.0
Anderson	23,723	67.5	0.0	0.0	Laurel	61,946	0.0	0.0	0.0
Ballard	3,565	0.0	0.0	0.0	Lawrence	14,905	0.0	0.0	0.0
Barren	40,990	0.0	0.0	0.0	Lee	6,826	0.0	1.0	1.1
Bath	10,425	0.0	1.1	0.0	Leslie	17,640	0.0	0.0	99.9
Bell	23,331	0.0	47.7	0.0	Letcher	17,640	14.6	12.3	18.9
Boone	131,626	0.0	0.0	0.0	Lewis	12,236	0.0	0.0	0.0
Bourbon	19,821	67.8	7.8	0.0	Lincoln	23,531	34.8	0.1	0.0
Boyd	48,085	0.0	0.0	0.0	Livingston	8,493	0.0	0.0	0.0
Boyle	30,450	0.1	0.0	0.0	Logan	27,019	0.0	0.0	0.0
Bracken	7,530	0.1	0.0	0.0	Lyon	8,080	0.0	0.0	0.0
Breathitt	12,257	0.0	99.3	0.0	Madison	92,069	0.2	25.8	0.0
Breckinridge	15,368	0.0	0.0	0.0	Magoffin	11,279	0.0	0.0	99.9
Bullitt	76,357	2.4	0.0	0.0	Marion	18,891	0.0	0.0	0.0
Butler	11,995	0.0	0.0	0.0	Marshall	28,259	0.0	0.0	0.0
Caldwell	12,473	0.0	0.0	0.0	Martin	11,165	0.0	0.0	99.9
Calloway	25,055	0.9	0.0	0.0	Mason	16,384	0.0	0.0	0.0
Campbell	89,151	0.3	0.0	0.0	McCracken	64,019	0.0	0.0	0.0
Carlisle	1,846	0.0	0.0	0.0	McCreary	15,174	0.0	0.0	0.0
Carroll	10,563	0.0	0.0	0.0	McLean	8,761	0.0	0.0	0.0
Carter	25,241	0.0	0.0	19.5	Meade	27,032	0.0	0.0	0.0
Casey	15,707	0.0	91.3	0.0	Menifee	5,899	0.0	0.1	0.0
Christian	59,242	0.0	0.0	0.0	Mercer	22,419	0.0	0.0	0.0
Clark	36,392	88.8	1.2	0.4	Metcalfe	10,060	0.0	0.0	0.0
Clay	18,744	0.1	0.0	95.5	Monroe	10,914	0.0	0.0	0.0
Clinton	9,169	0.0	0.0	0.0	Montgomery	28,001	0.1	78.9	0.0
Crittenden	8,468	0.0	0.0	34.7	Morgan	12,888	2.4	0.4	0.1
Cumberland	5,572	0.0	0.0	0.0	Muhlenberg	30,149	0.0	15.6	0.0
Daviess	97,289	0.0	0.0	0.0	Nelson	39,848	25.8	0.0	0.0
Edmonson	11,868	0.0	0.0	0.0	Nicholas	7,280	28.3	0.1	0.0
Elliott	6,731	54.3	0.0	0.0	Ohio	23,264	0.0	0.0	0.0
Estill	14,011	0.2	2.9	0.0	Oldham	58,868	0.0	0.0	0.0
Fayette	284,471	0.4	0.0	0.0	Owen	10,111	0.3	0.0	0.0
Fleming	14,903	0.0	0.0	0.0	Owsley	3,885	0.3	0.0	99.4
Floyd	34,608	0.0	2.0	0.0	Pendleton	12,085	61.0	0.0	0.0
Franklin	51,558	0.0	0.0	0.0	Perry	26,657	0.1	89.8	0.4
Fulton	5,701	0.0	0.0	0.0	Pike	47,450	0.0	0.3	0.0
Gallatin	8,520	0.0	0.0	0.0	Powell	12,088	0.0	99.7	0.2
Garrard	16,734	74.3	0.3	0.0	Pulaski	63,535	0.0	0.0	0.0
Grant	24,356	0.0	0.0	0.0	Robertson	1,770	0.1	0.0	0.0
Graves	24,728	2.9	0.0	0.0	Rockcastle	15,768	9.5	0.1	0.0
Grayson	26,092	0.0	0.0	0.0	Rowan	22,045	0.0	0.0	0.0
Green	10,894	0.0	0.0	0.0	Russell	17,461	0.0	0.1	0.0
Greenup	27,960	0.0	0.0	0.0	Scott	53,484	71.1	0.0	0.0
Hancock	8,957	0.0	0.0	0.0	Shelby	45,812	56.5	0.0	0.0
Hardin	108,897	0.0	0.0	0.0	Simpson	17,576	59.5	0.0	0.0
Harlan	25,578	54.3	0.0	41.0	Spencer	18,323	2.6	0.0	0.0
Harrison	18,488	0.1	0.0	0.0	Taylor	25,009	0.0	0.0	0.0
Hart	18,923	0.0	0.0	0.0	Todd	11,845	0.0	0.0	0.0
Henderson	44,239	0.0	0.0	0.0	Trigg	13,546	0.0	0.0	0.0
Henry	11,462	0.0	0.0	0.0	Trimble	7,851	0.0	6.0	0.0
Hickman	1,685	0.0	0.0	0.0	Union	13,265	0.0	0.0	0.0
Hopkins	42,860	0.0	0.1	0.0	Warren	126,736	0.0	0.0	0.0
Jackson	12,335	98.1	0.0	0.7	Washington	11,687	0.0	0.0	0.0
Jefferson	774,579	0.0	0.0	0.0	Wayne	17,639	0.0	0.0	0.0
Jessamine	52,828	86.6	0.0	0.0	Webster	12,782	0.0	26.0	0.0
Johnson	21,730	0.0	0.0	0.2	Whitley	35,326	0.0	0.0	0.0
Kenton	165,908	0.0	0.0	0.0	Wolfe	5,828	0.0	98.1	0.0
Knott	13,557	0.0	1.6	0.0	Woodford	19,320	0.6	0.0	0.0

Figure 20. Water supply risk as number of people served by minimal to low drought hazard water systems

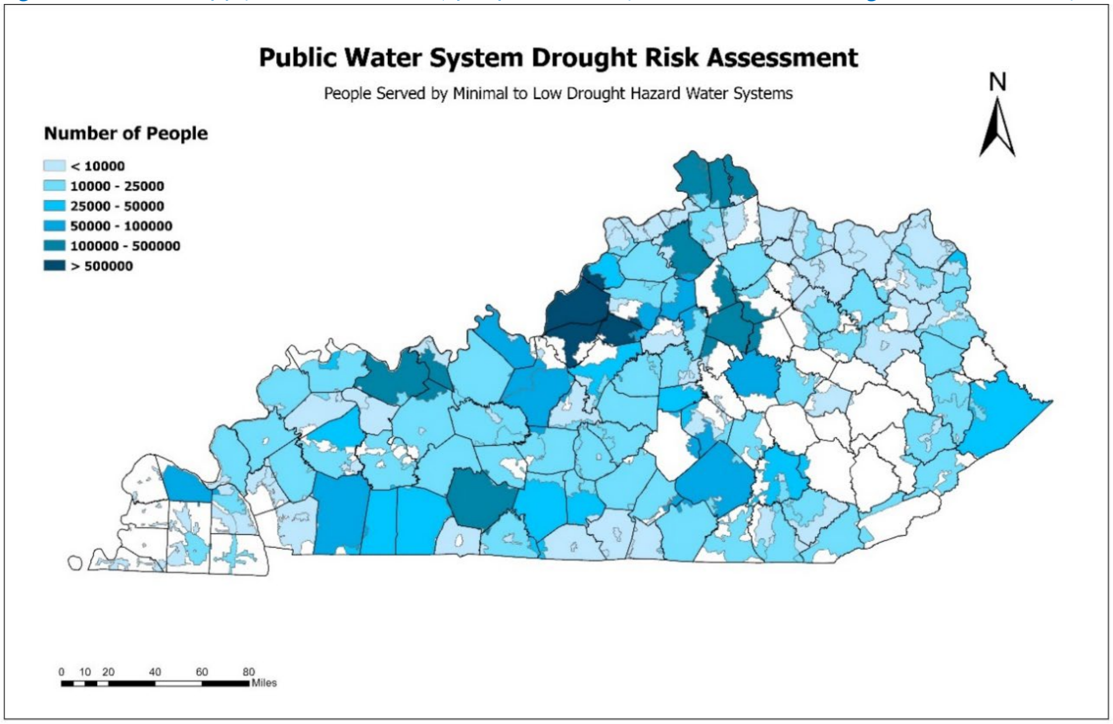


Figure 21. Water supply risk as number of people per county served by low to minimal to low drought hazard water systems

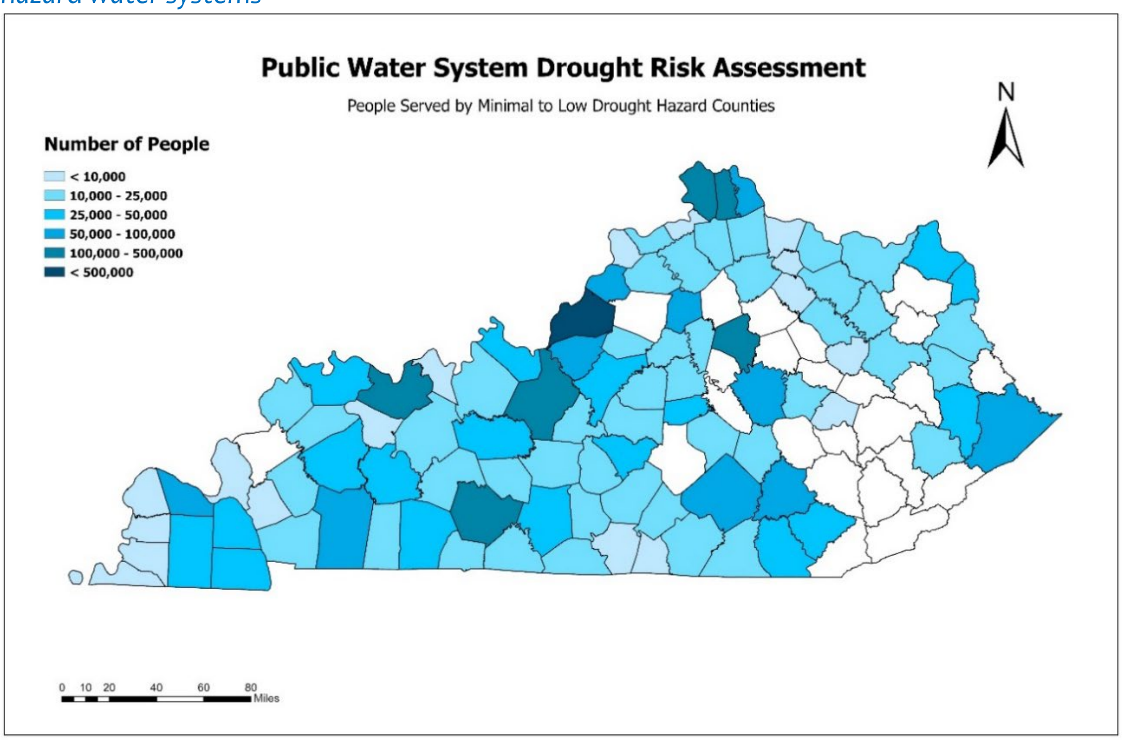


Table 12. Water supply risk as percentage of people per county served by minimal to low drought hazard water systems.

	Population	Percentage of Served Population			Population	Percentage of Served Population	
County	Served	Minimal	Low	County	Served	Minimal	Low
Adair	17,044	1.5	98.2	Knox	28,836	80.2	19.8
Allen	19,996	73.5	26.5	Larue	14,800	60.1	11.9
Anderson	23,723	30.5	2.0	Laurel	61,946	100.0	0.0
Ballard	3,565	100.0	0.0	Lawrence	14,905	40.7	59.3
Barren	40,990	94.9	5.1	Lee	6,826	0.0	98.0
Bath	10,425	78.6	20.3	Leslie	17,640	0.0	0.0
Bell	23,331	52.3	0.0	Letcher	17,640	54.1	0.1
Boone	131,626	100.0	0.0	Lewis	12,236	51.6	48.4
Bourbon	19,821	0.0	24.4	Lincoln	23,531	0.0	65.1
Boyd	48,085	90.8	9.2	Livingston	8,493	100.0	0.0
Boyle	30,450	0.0	99.9	Logan	27,019	100.0	0.0
Bracken	7,530	96.6	3.4	Lyon	8,080	100.0	0.0
Breathitt	12,257	0.0	0.7	Madison	92,069	74.0	0.1
Breckinridge	15,368	100.0	0.0	Magoffin	11,279	0.1	0.0
Bullitt	76,357	97.6	0.0	Marion	18,891	1.0	99.1
Butler	11,995	99.9	0.1	Marshall	28,259	84.6	15.5
Caldwell	12,473	100.0	0.0	Martin	11,165	0.0	0.1
Calloway	25,055	99.2	0.9	Mason	16,384	92.5	7.5
Campbell	89,151	98.0	1.6	McCracken	64,019	100.0	0.0
Carlisle	1,846	100.0	0.0	McCreary	15,174	100.0	0.0
Carroll	10,563	100.0	0.0	McLean	8,761	13.2	86.8
Carter	25,241	6.8	73.8	Meade	27,032	100.0	0.0
Casey	15,707	0.6	8.2	Menifee	5,899	99.9	0.1
Christian	59,242	100.0	0.0	Mercer	22,419	43.4	56.6
Clark	36,392	0	9.7	Metcalfe	10,060	78.7	21.3
Clay	18,744	4.4	0.0	Monroe	10,914	4.9	95.1
Clinton	9,169	98.7	1.4	Montgomery	28,001	21.0	78.9
Crittenden	8,468	65.3	0.0	Morgan	12,888	96.4	0.8
Cumberland	5,572	0.0	100.0	Muhlenberg	30,149	84.4	0.0
Daviess	97,289	100.0	0.0	Nelson	39,848	4.3	70.0
Edmonson	11,868	1.6	98.4	Nicholas	7,280	0.0	71.6
Elliott	6,731	8.0	37.7	Ohio	23,264	88.8	11.2
Estill	14,011	0.0	96.9	Oldham	58,868	98.9	1.1
Fayette	284,471	0.0	99.6	Owen	10,111	13.7	86.0
Fleming	14,903	78.9	21.2	Owsley	3,885	0.0	0.3
Floyd	34,608	96.1	0.1	Pendleton	12,085	4.8	34.2
Franklin	51,558	4.3	95.7	Perry	26,657	9.75	0.0
Fulton	5,701	50.6	49.4	Pike	47,450	22.8	76.9
Gallatin	8,520	95.9	4.1	Powell	12,088	0.0	0.1
Garrard	16,734	0.0	25.4	Pulaski	63,535	0.0	100.0
Grant	24,356	61.1	38.9	Robertson	1,770	0.0	99.9
Graves	24,728	87.1	10.1	Rockcastle	15,768	2.4	88.0
Grayson	26,092	25.9	74.1	Rowan	22,045	100.0	0.0
Green	10,894	92.3	7.7	Russell	17,461	96.9	3.1
Greenup	27,960	85.1	14.9	Scott	53,484	0.0	28.9
Hancock	8,957	100.0	0.0	Shelby	45,812	33.4	10.2
Hardin	108,897	99.6	0.4	Simpson	17,576	40.5	0.0
Harlan	25,578	4.7	0.0	Spencer	18,323	96.4	0.9
Harrison	18,488	0.0	99.9	Taylor	25,009	99.8	0.2
Hart	18,923	3.9	96.1	Todd	11,845	100.0	0.0
Henderson	44,239	100.0	0.0	Trigg	13,546	100.0	0.0
Henry	11,462	0.5	0.0	Trimble	7,851	29.1	64.9
Hickman	1,685	100.0	0.0	Union	13,265	100.0	0.0
Hopkins	42,860	91.9	8.0	Warren	126,736	99.7	0.3
Jackson	12,335	1.1	0.1	Washington	11,687	91.9	8.1
Jefferson	774,579	100.0	0.0	Wayne	17,639	0.3	99.7
Jessamine	52,828	0.0	13.4	Webster	12,782	74.0	0.0
Johnson	21,730	4.6	95.1	Whitley	35,326	48.9	51.1
Kenton	165,908	100.0	0.0	Wolfe	5,828	1.5	0.4
Knott	13,557	98.4	0.0	Woodford	19,320	0.0	99.4

Figure 22. Number of Hospitals and Long-term care facilities (by numbers of beds) as indicators of human health risks

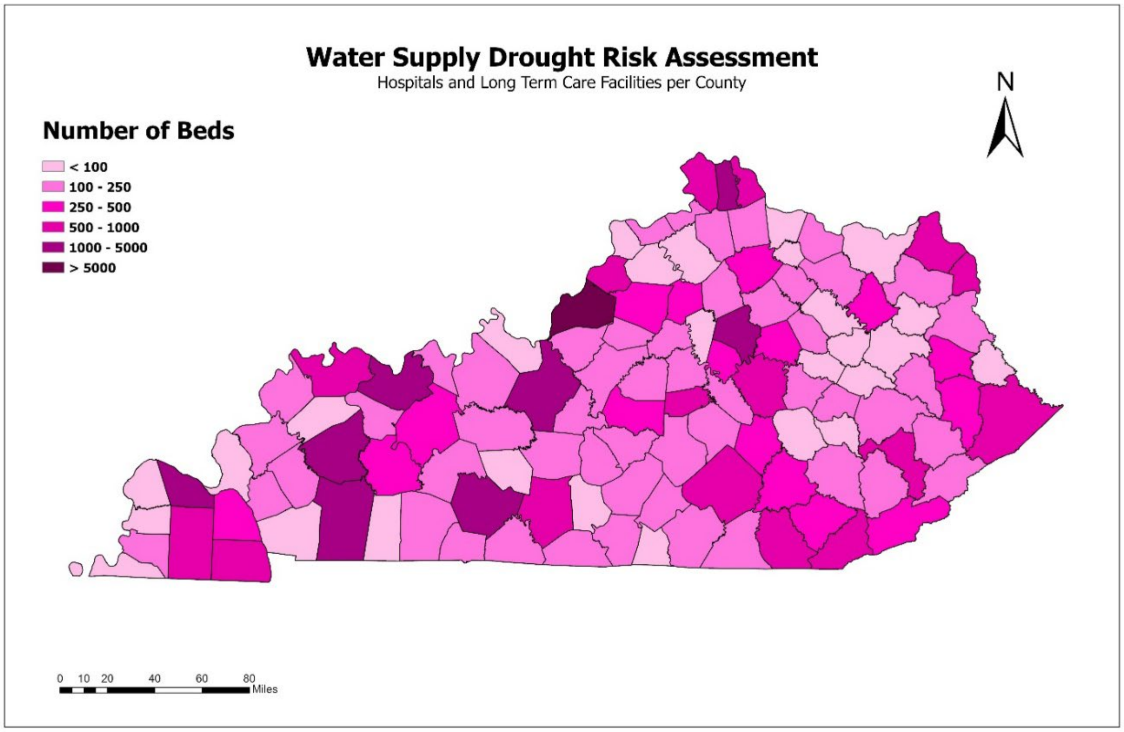


Figure 23. Number of Hospitals and Long-term care facilities (by number of beds) per Water Treatment Systems

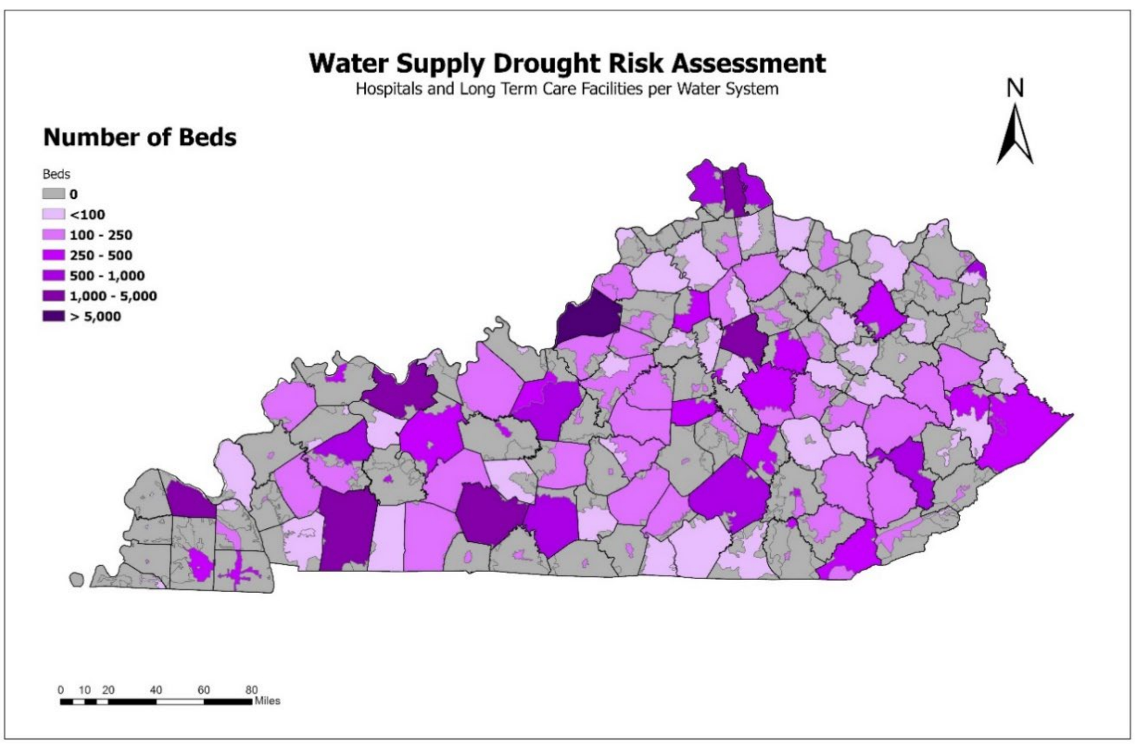


Figure 24. Human health risk: Hospital and long-term care beds served by moderate to extreme drought by county.

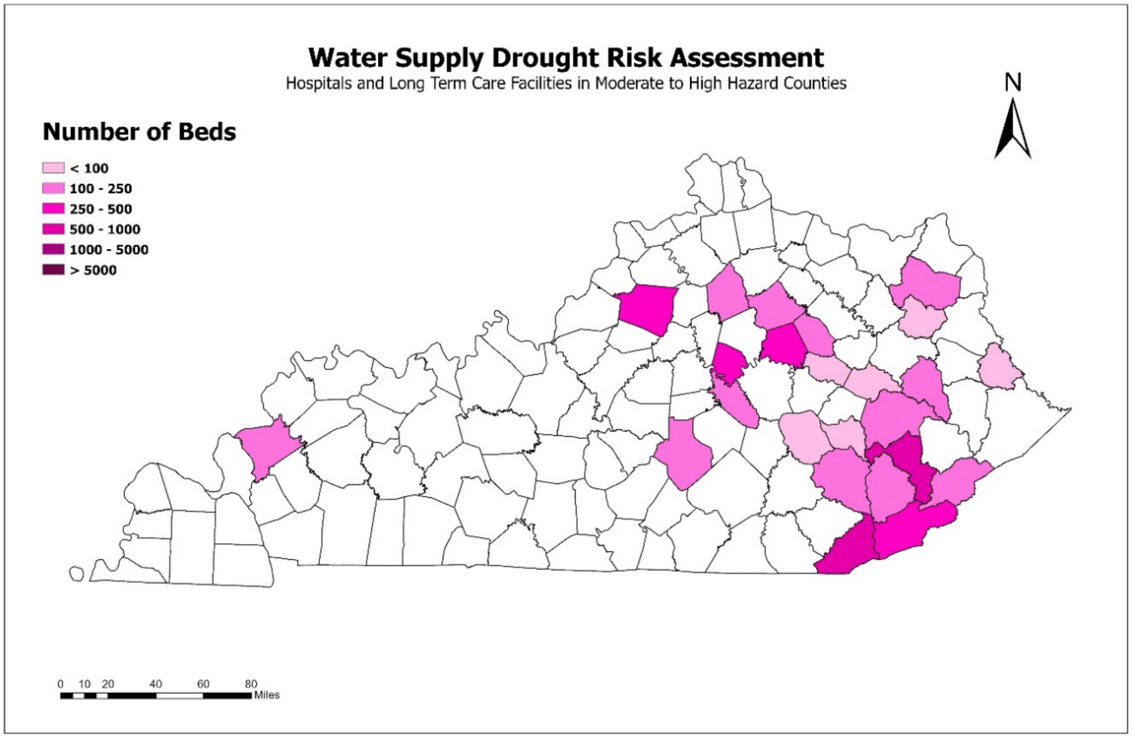


Figure 25. Human health risk: Hospital and long-term care beds served by moderate to extreme drought hazard water systems.

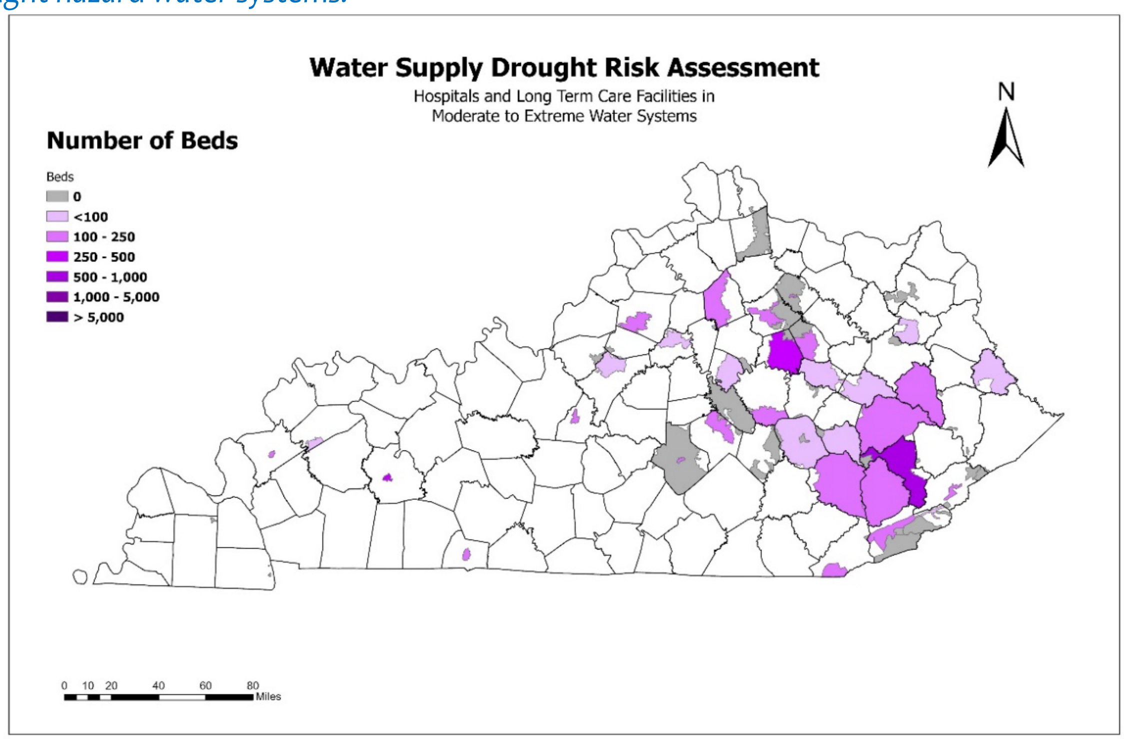


Figure 26. State office building by county

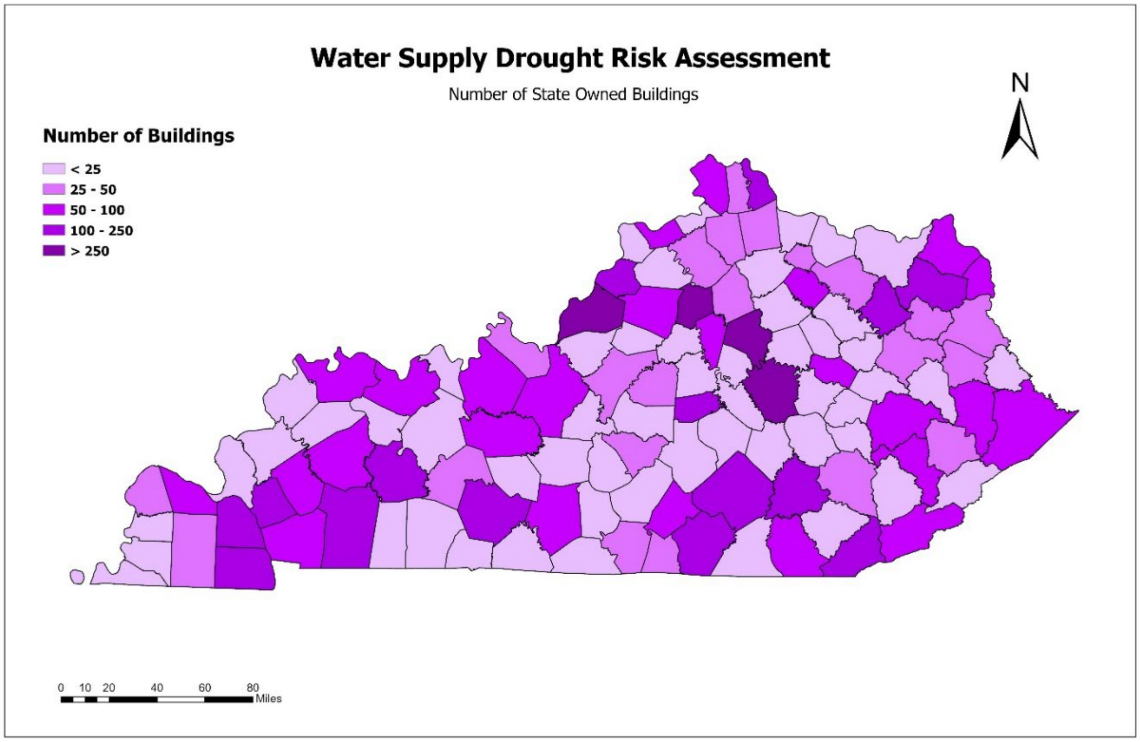


Figure 27. State office building by water system

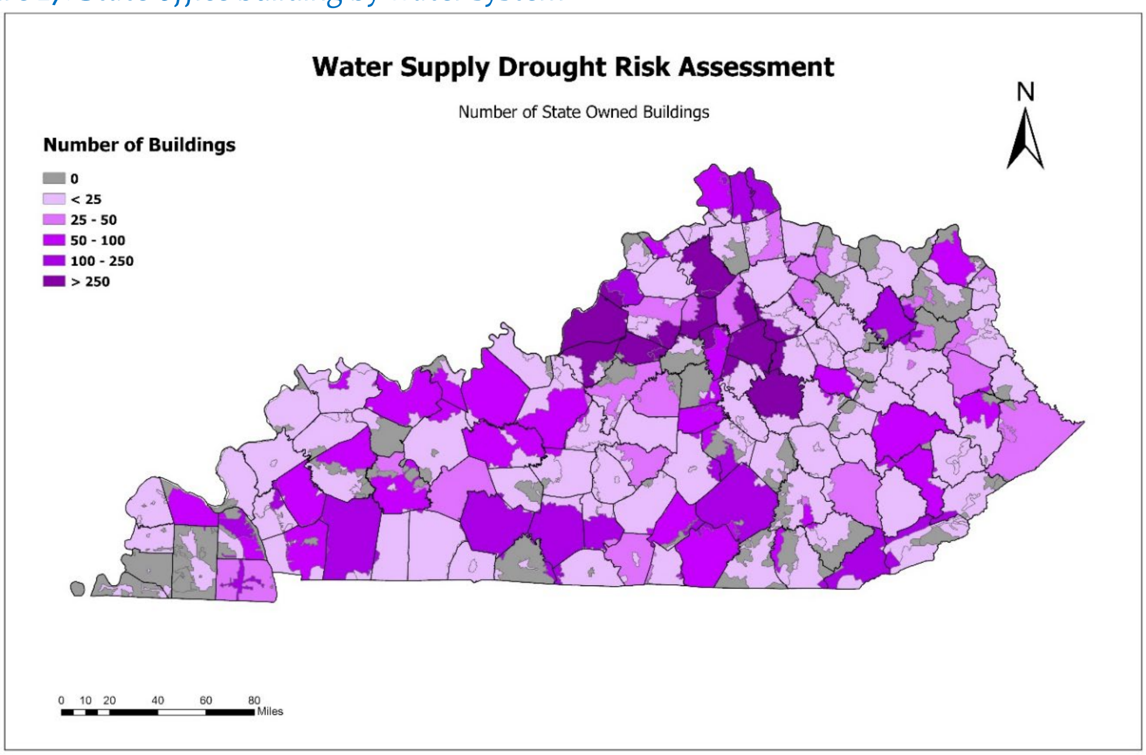


Figure 28. Number of state office buildings in moderate to high hazard counties

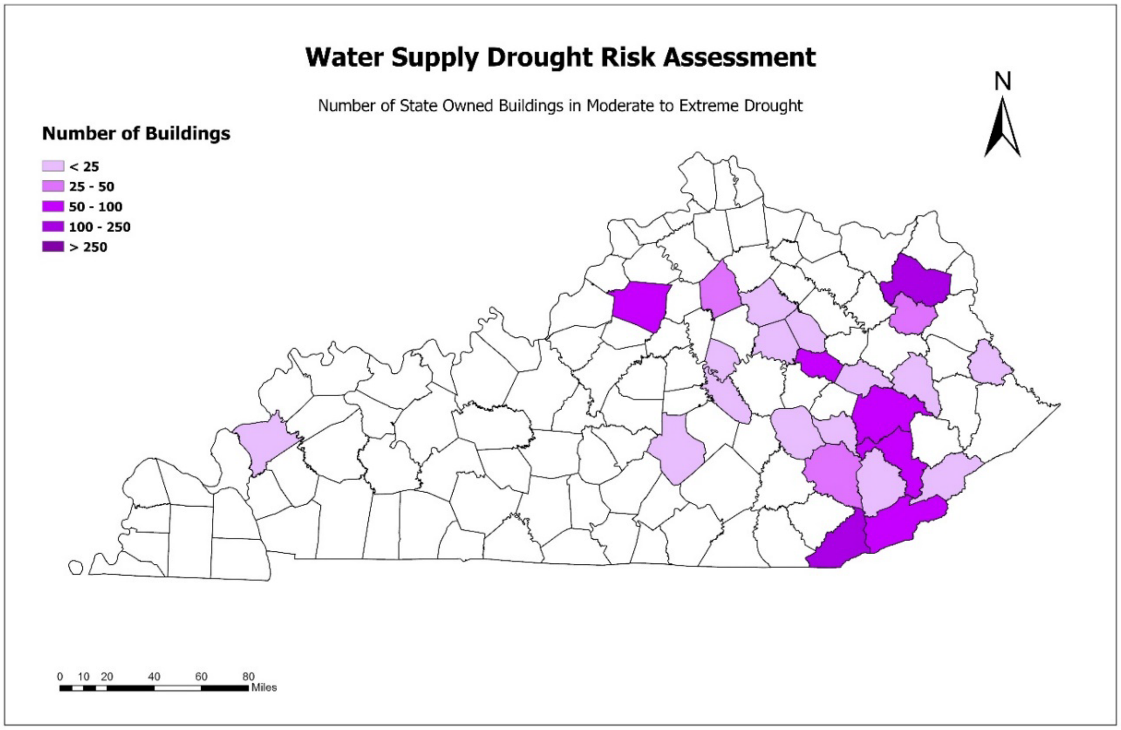


Figure 29. Number of state office buildings in moderate to high hazard water systems

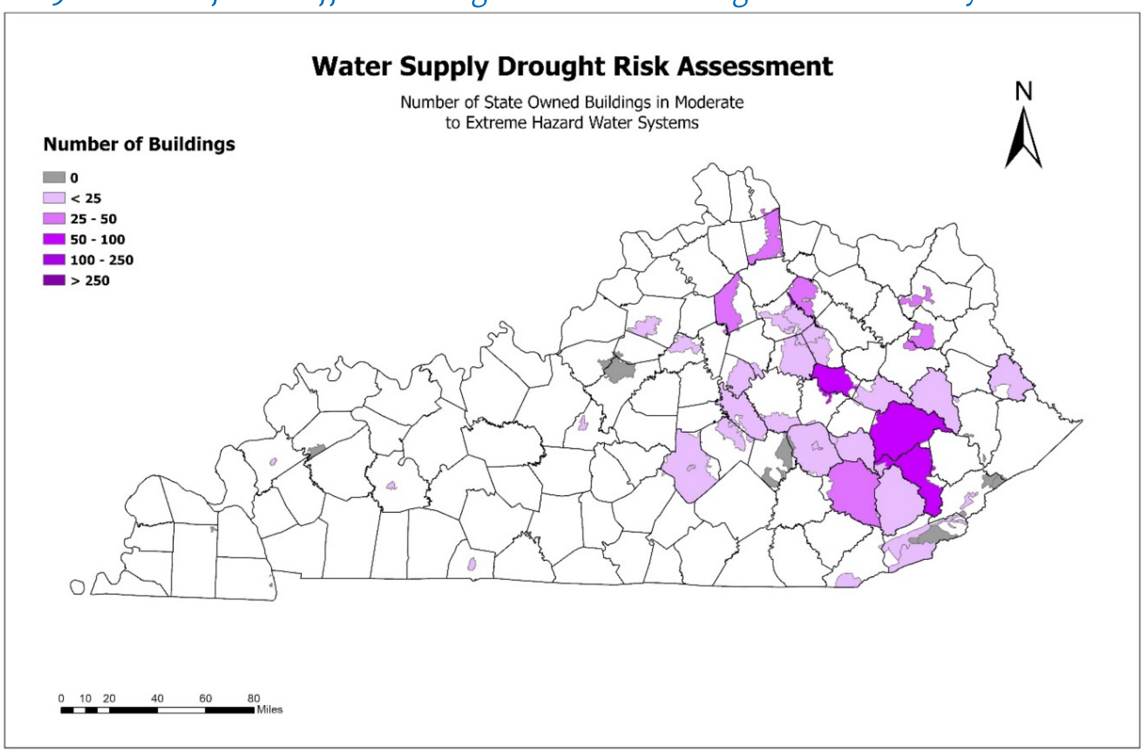


Table 13. Number of state office buildings in moderate to high hazard water systems

Drought Hazard	Number of Beds	% of all Beds
All	45696	--
Moderate to Extreme	4832	10.5%
High to Extreme	2745	6.0%
Extreme	992	2.2%

Agricultural Risk Assessment

Crop Risk Assessment

The drought risk assessment map for the drought soil hazard is based on the assumption that soils with superior moisture storage and release characteristics as defined by NRCS will support higher plant productivity during moderate droughts. These maps were created using a ranking system as outlined below:

Soil Hazard Score = Average (Infiltration, Water Movement, Water Supply)

> *Infiltration Score = Average (Representative Average Slope, Hydrologic Soil Group, Soil Surface Sealing)*
>
> *Water Movement Score = Ksat*
>
> *Water Supply Score = Average (Available Water Capacity, Depth to Restrictive Layer, and Depth to Water Table)*

Once created the soil drought hazard layer could be analyzed for soil moisture characteristics underlying any class of land use or cropping system.

The Soil Drought Hazard Map reflects a soils drought vulnerability from a moisture retention and availability perspective. It does not take into account other factors that contribute to how fertile a soil is. The data used to create these maps is based on NRCS soil surveys, which are produced at a county level. As a result, there are some places where hazard levels do not flow smoothly over county boundaries due to differences in how a soil, or soils, were characterized in that particular soil survey. Grey areas indicate that no soil data was available. This includes lakes, heavily urbanized areas, or strip mining.

This risk assessment applies to droughts of moderate and severe intensity. Even the most drought resilient soil has a finite amount of water storage which will be depleted as drought conditions intensify and persist. Other variables, such as extreme heat can exacerbate conditions and cause soil moisture to be depleted even quicker. The drought in western Kentucky in 2012 was a great example of this. However, it is rare in to have no rainfall for weeks on end in Kentucky. Typically some rainfall occurs during drought, just lower amounts then normal. During the summer, most precipitation comes from convective thunderstorms, resulting in heavy rainfall during a short amount of time. A soil that is able to absorb this precipitation quickly and efficiently is going to be more drought resilient, as it can take advantage of well-timed precipitation events and provide plants with additional water until drought conditions relent.

The first thing that stands out is how well the soil hazard level map matches up with the physiological regions of the state. Soils in the Outer Bluegrass, Eastern Coal Fields, and Western Coal Fields are generally have a higher hazard level compared to the Inner Bluegrass, Mississippian Plateau and the Knobs. The Jackson Purchase generally has low hazard level soils, but some higher areas, this is due to fragipans, which limit the depth of the soil roots can access.

There are three areas in the state that are major areas for crop production, the Purchase, Mississippian Plateau, and the Ohio River Alluvium between Henderson and Owensboro. These areas are relatively flat with fertile soils, perfect for planting row crops. All three of these areas generally have a lower hazard level. The major pasture and hay areas in Kentucky are located in the inner and outer bluegrass and extending south into the eastern Mississippian Plateau generally between Bowling Green and Lake Cumberland. These are areas that are generally hillier than the major cropped areas, making it more suited for pasture. This section of the Mississippian Plateau does have a higher hazard level than areas further east, but still generally moderately low to moderately high. The outer bluegrass however has a much higher hazard with areas generally having a high hazard and even extreme. The inner bluegrass is a doughnut hole of low hazard soils in the middle of the outer bluegrass. This area is home to many thoroughbred farms.

Figure 30. Soil Drought Hazard for all of Kentucky Soils

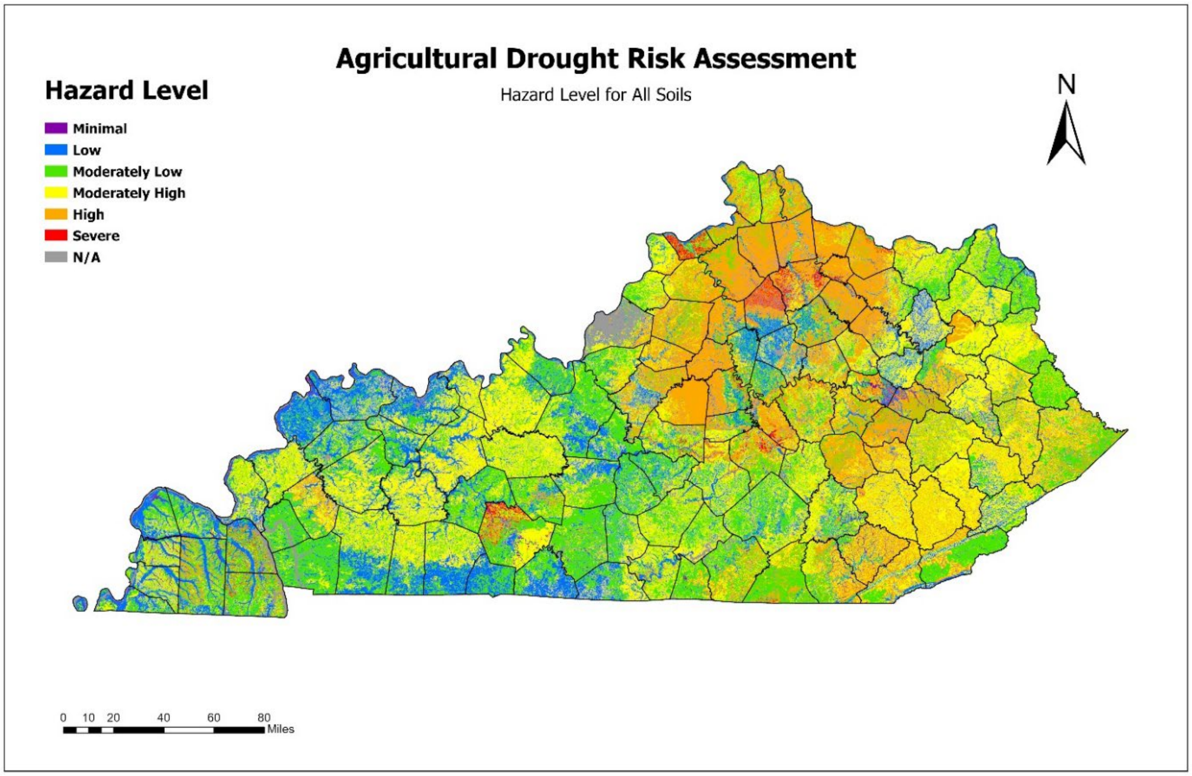


Figure 31. Soil Drought Hazard by county

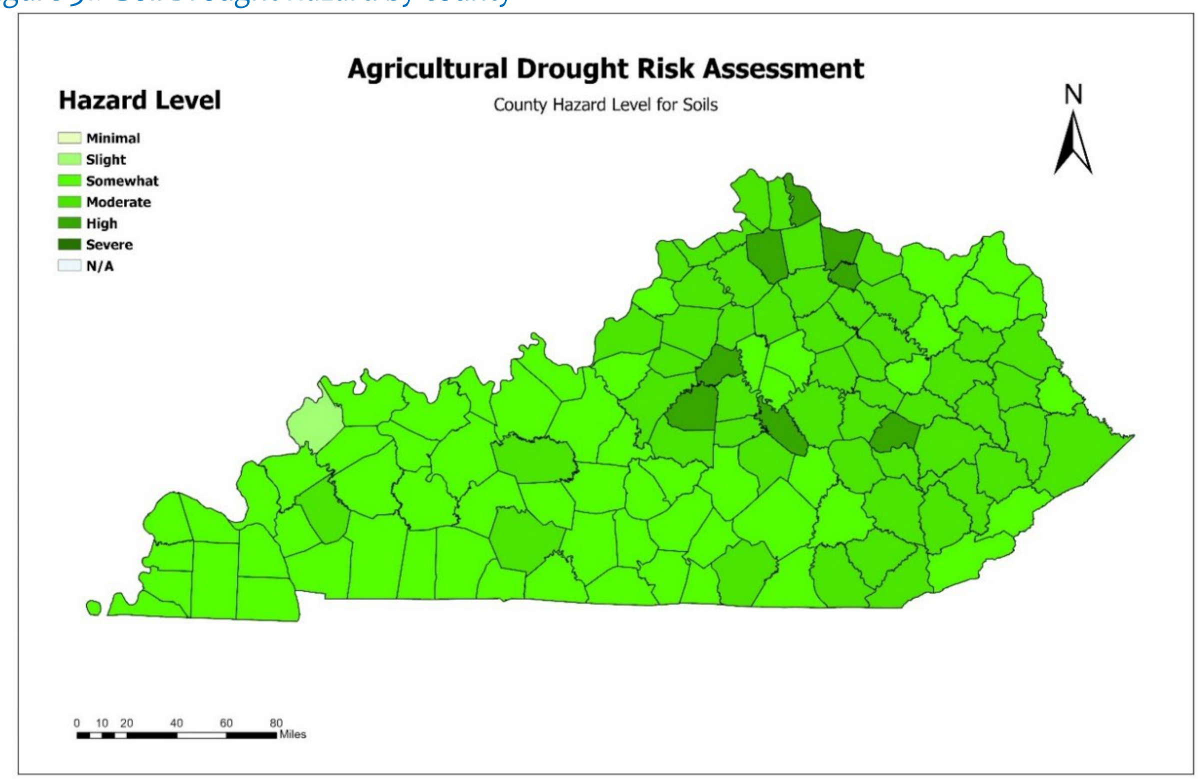


Figure 32. Soil Drought Hazard for soils used for producing pasture and hay

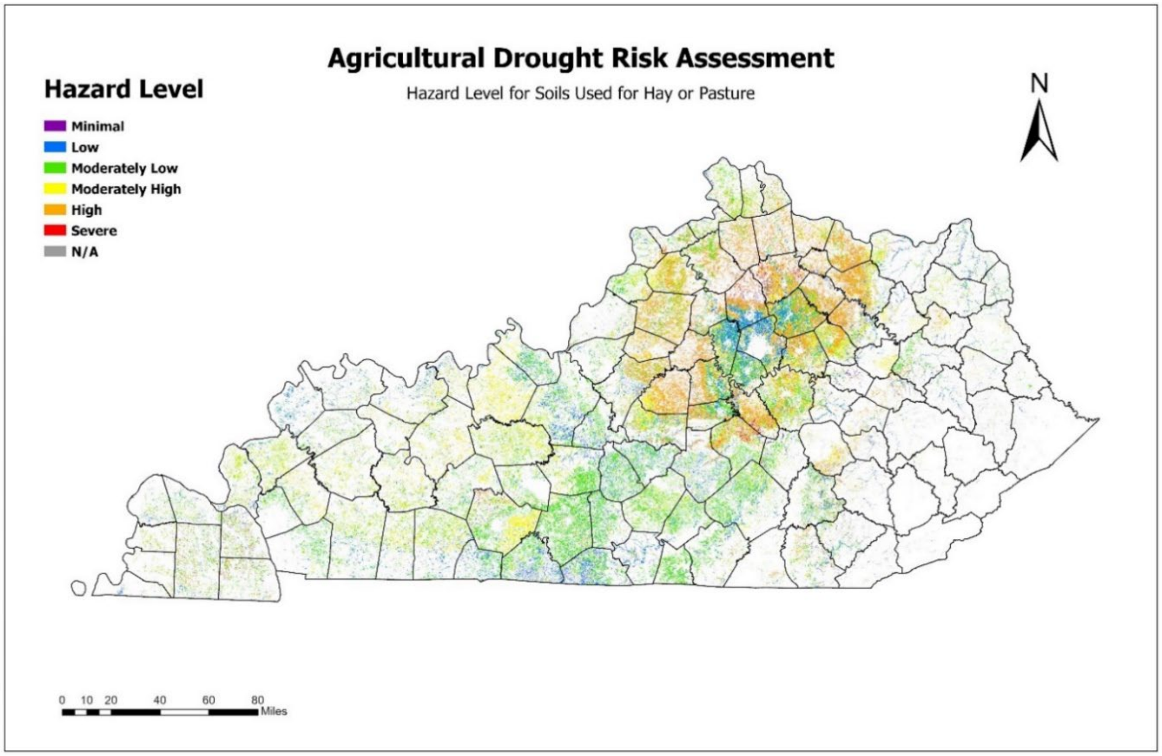


Figure 33. Soil Drought Hazard for soils used for crop production

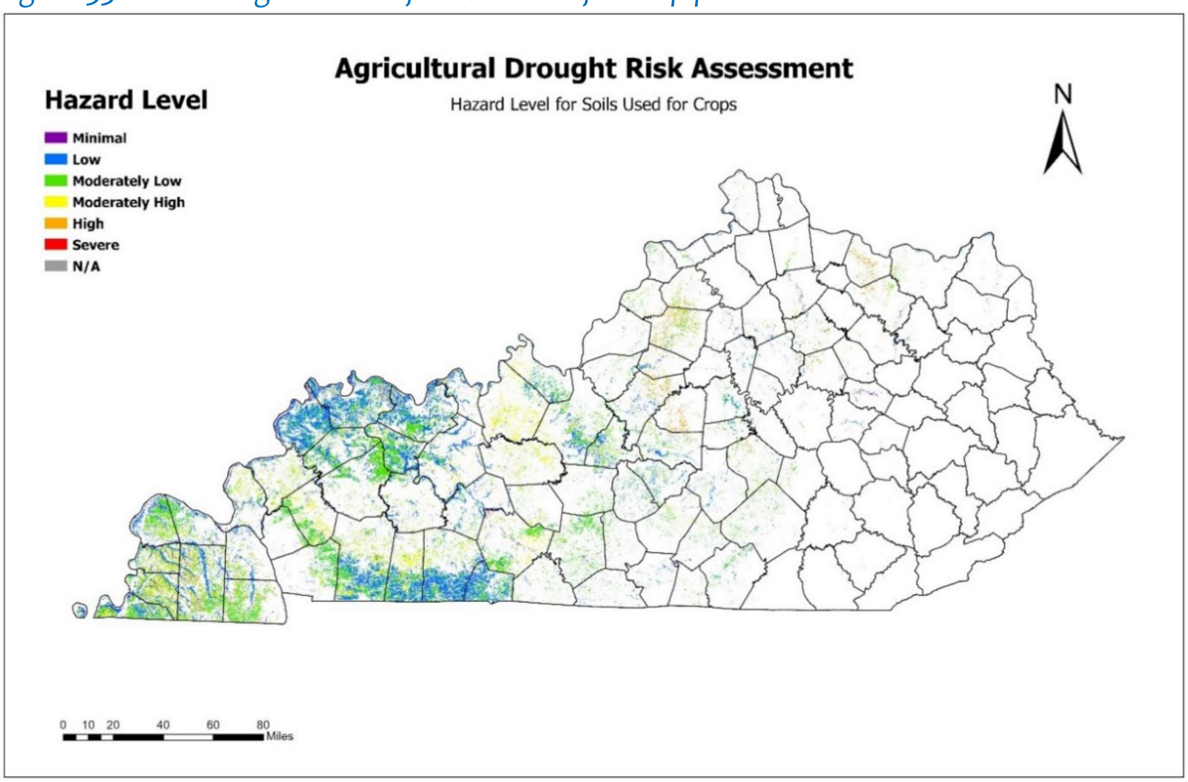


Figure 34. Soil Drought Hazard for soils used for producing pasture and hay by county

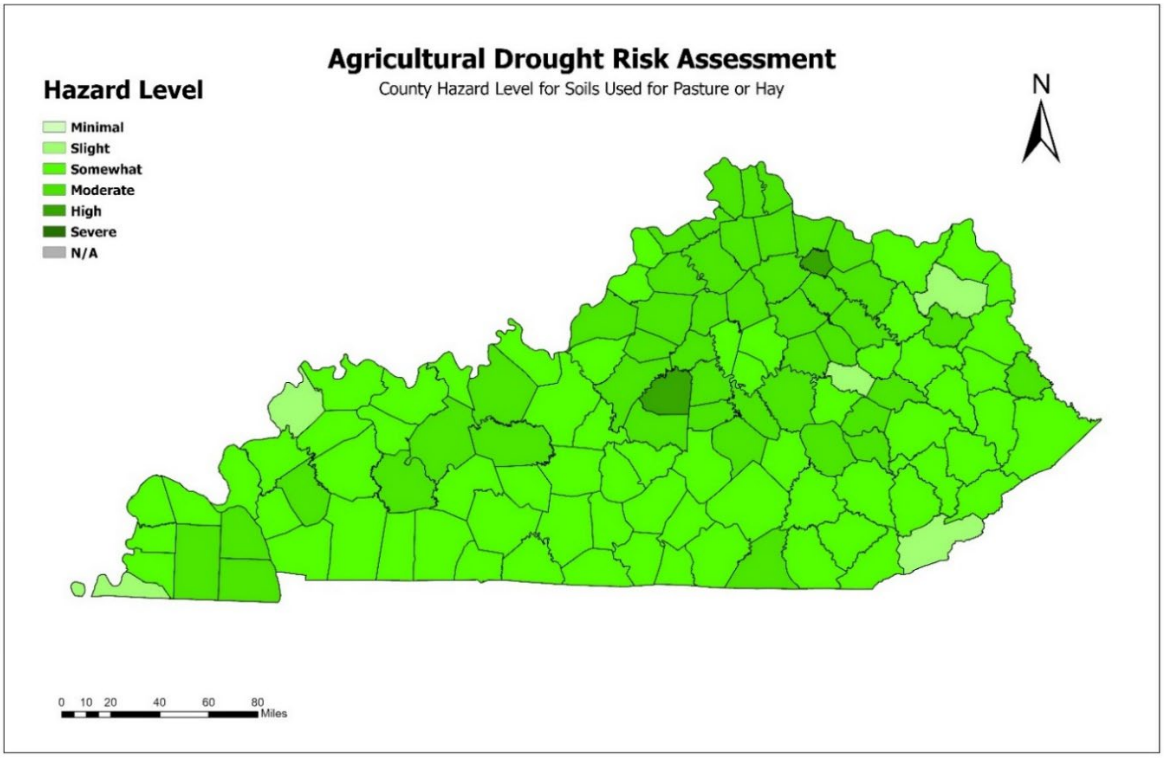


Figure 35. Soil Drought Hazard for soils used for crop production by county

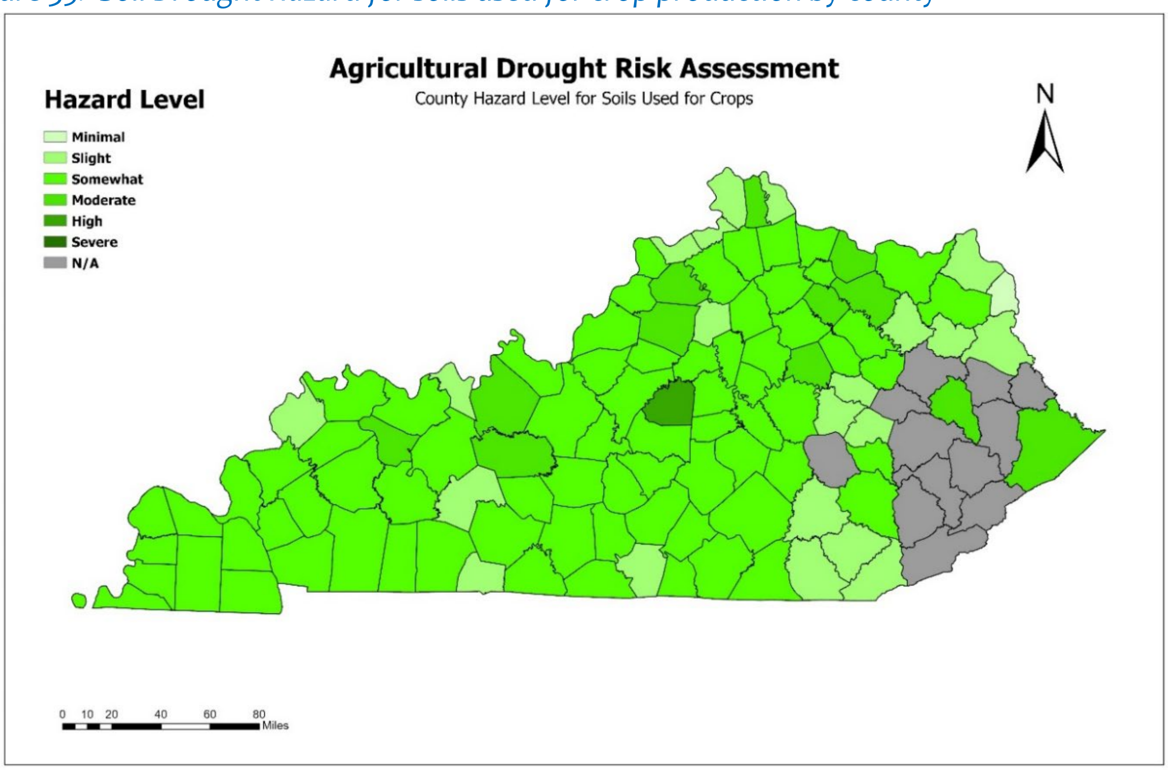
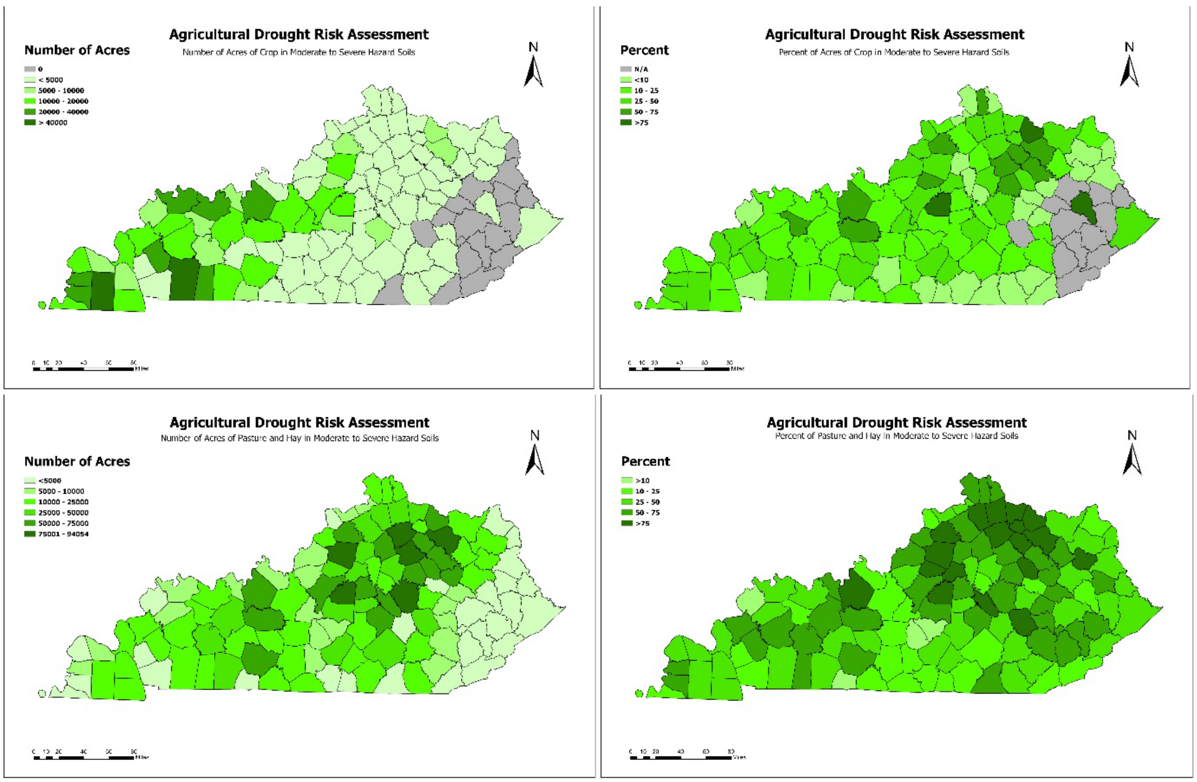


Figure 36. Number of row crop or pasture acres (left-hand column) utilizing Moderate to Severe Hazard soils; Percent of row crop or pastures acres (right-hand column) in each county that area utilizing Moderate to Severe Hazard soils.

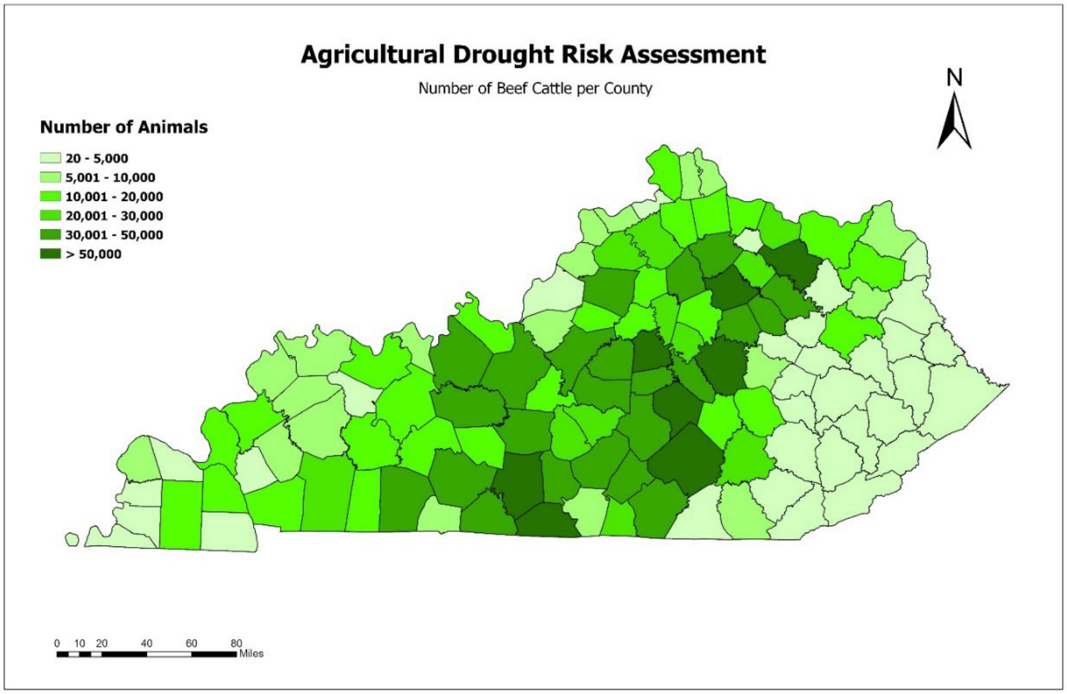


Livestock Risk Assessment

Unlike previous maps, areas with no PWS are included in livestock water system maps and county maps. It is assumed that these areas are self-served, but it is possible that farms could haul water in as on farm sources dry up. This is especially true for cattle, both beef and dairy, since small ponds are commonly used for water sources. These ponds are typically drought vulnerable and farmers have to use alternative sources to provide water for cattle. The most common source is to use city water, including water hauling stations, which could be used by cattle farmers who live in unserved areas. The use of water from a public water system to provide water for cattle can put additional strain on systems already dealing with increased usage and/or diminishing sources during a drought. It also should be noted, when compared to row crops, pasture and hay used to feed cattle tend to be located on soils that are more drought vulnerable. When compared to other livestock, cattle are also more likely to be found in areas served by water systems that have a moderate to extreme drought hazard.

Poultry houses use a significant amount of water as it is used to cool the air in the houses in addition to providing drinking water to the birds. Drought conditions tend to lead to hotter temperatures which would lead to increased amounts of water being used for cooling during a drought. However, there is only water system with a moderate to extreme drought risk that has poultry houses located in it, so the overall risk to poultry systems is low. Most hog farms are located in the service areas of water systems with minimal to low hazards. A few farms are located in services areas with moderate to extreme hazards.

Figure 37. Total Number of Beef Cattle per County



Source: USDA National Agricultural Statistics Service

Figure 38. Number of Beef Cattle per Water System

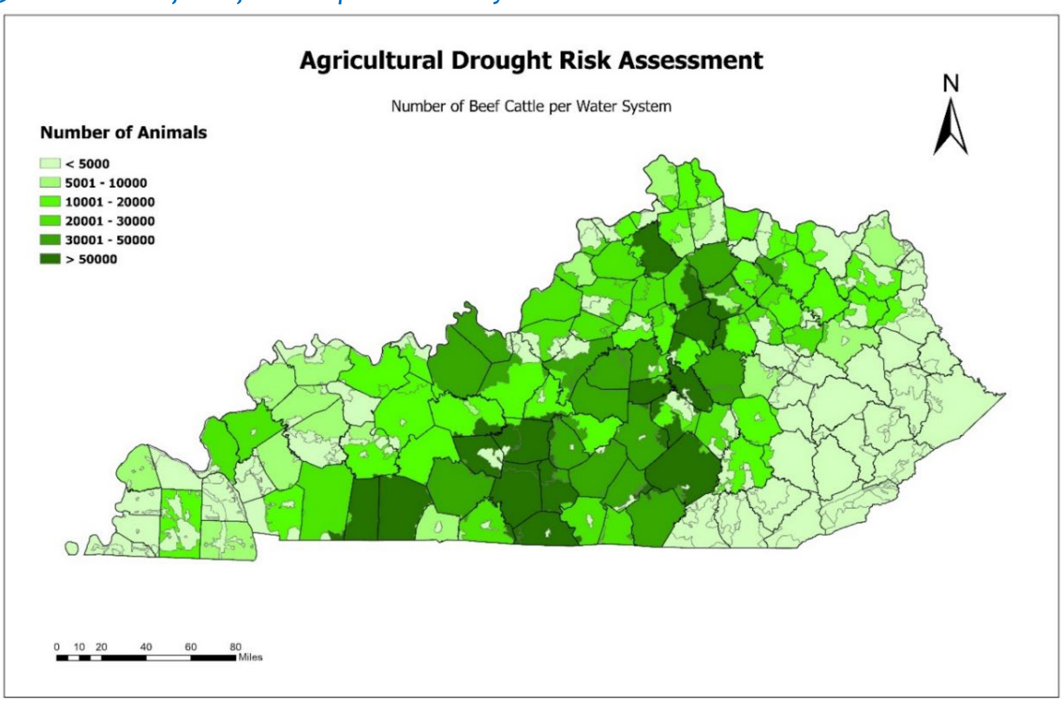


Figure 39. Number of Beef Cattle in Moderate to Severe Hazard Counties

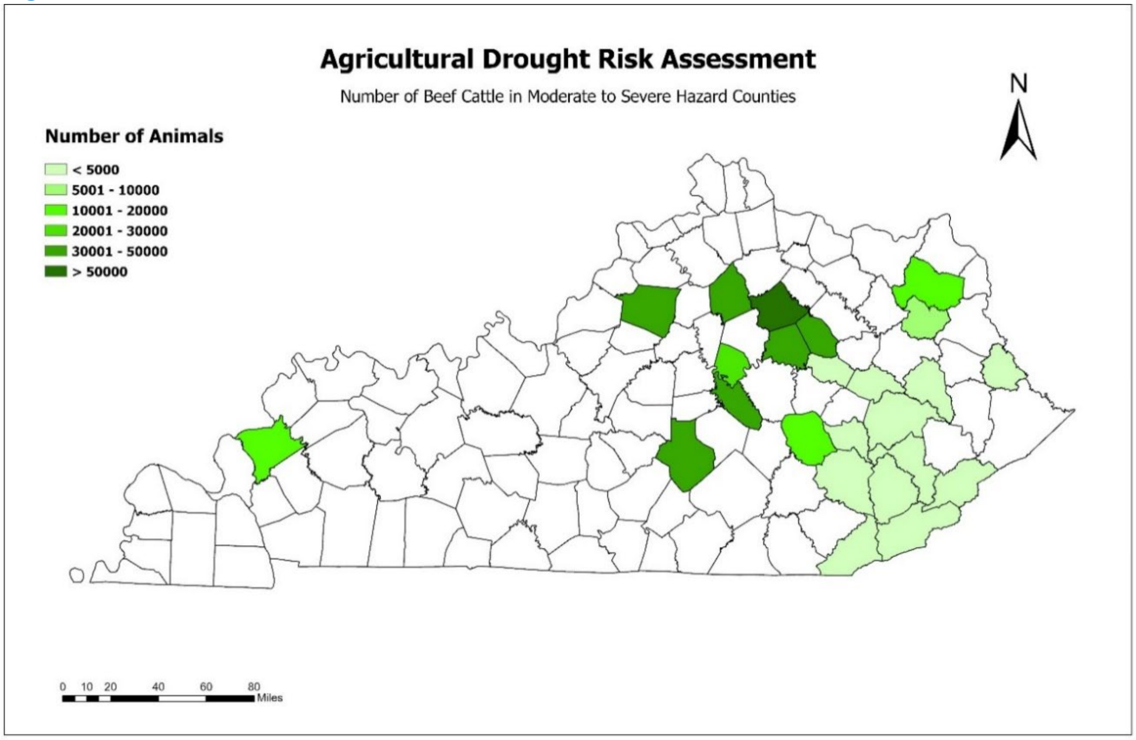


Figure 40. Number of Beef Cattle in Moderate to Severe Hazard Water Systems

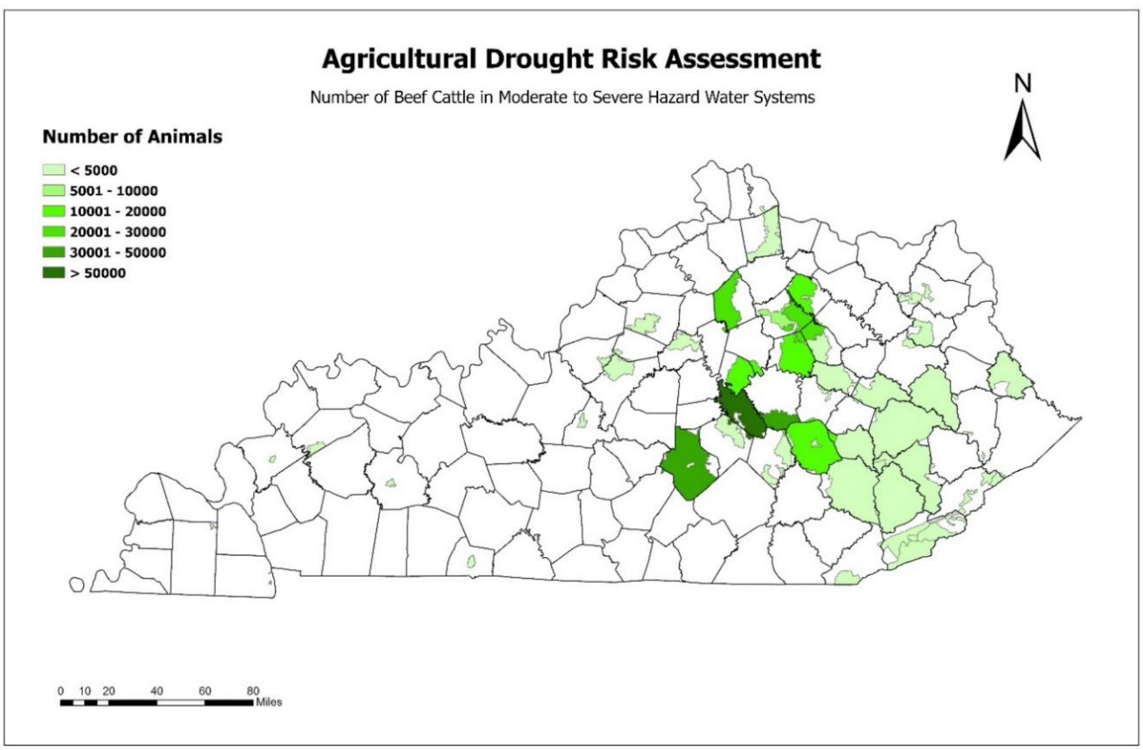
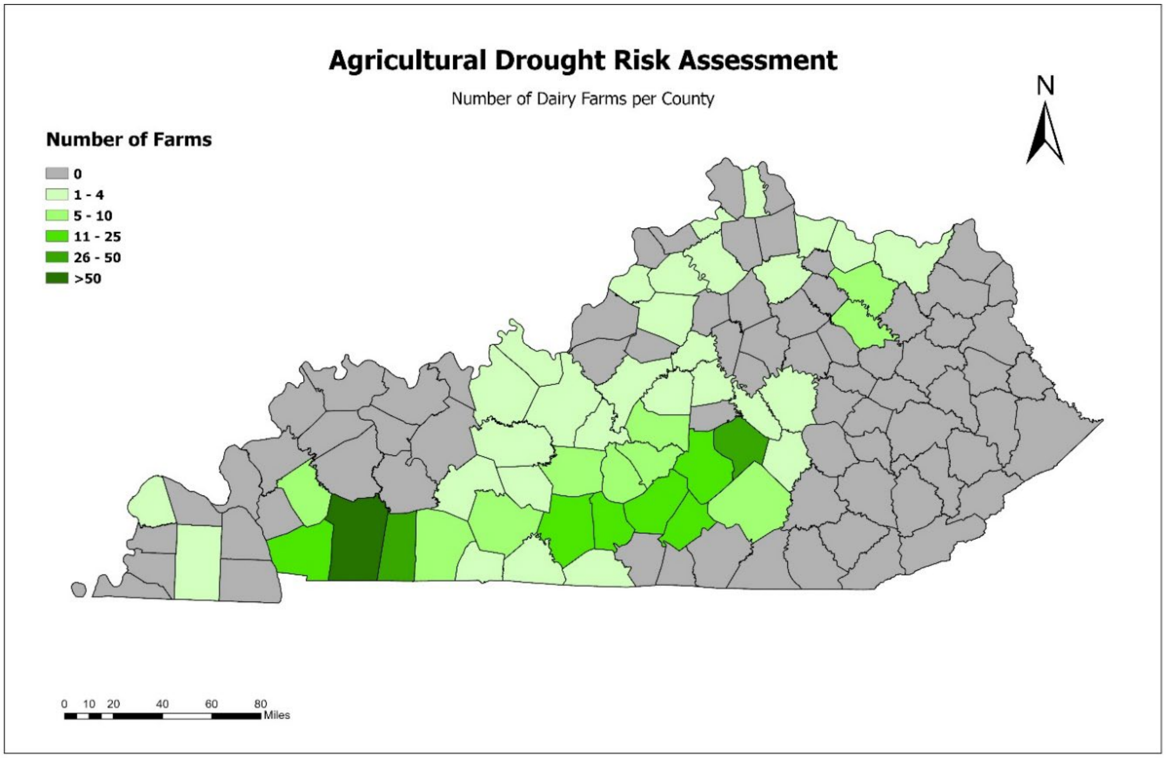


Figure 41. Number of Dairy Cattle per County



Dairy Numbers Provided by KY Milk Safety Branch

Figure 42. Number of Dairy Cattle in a Moderate to Severe Hazard County

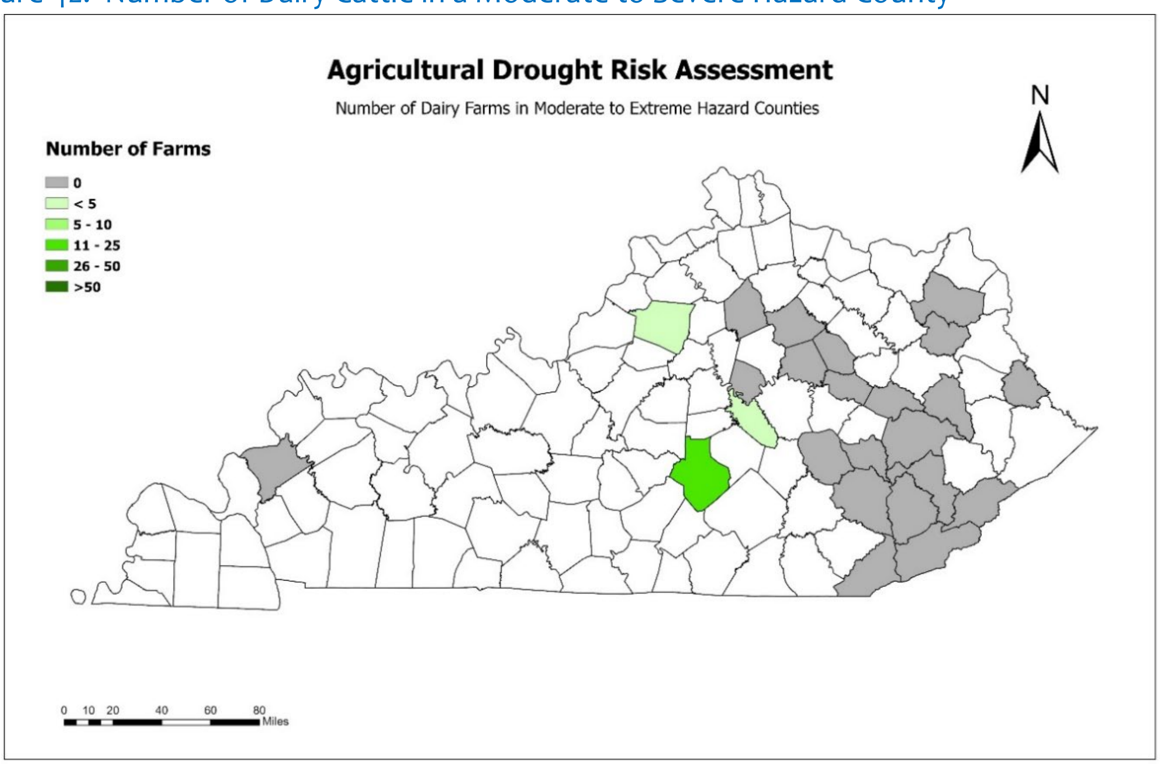
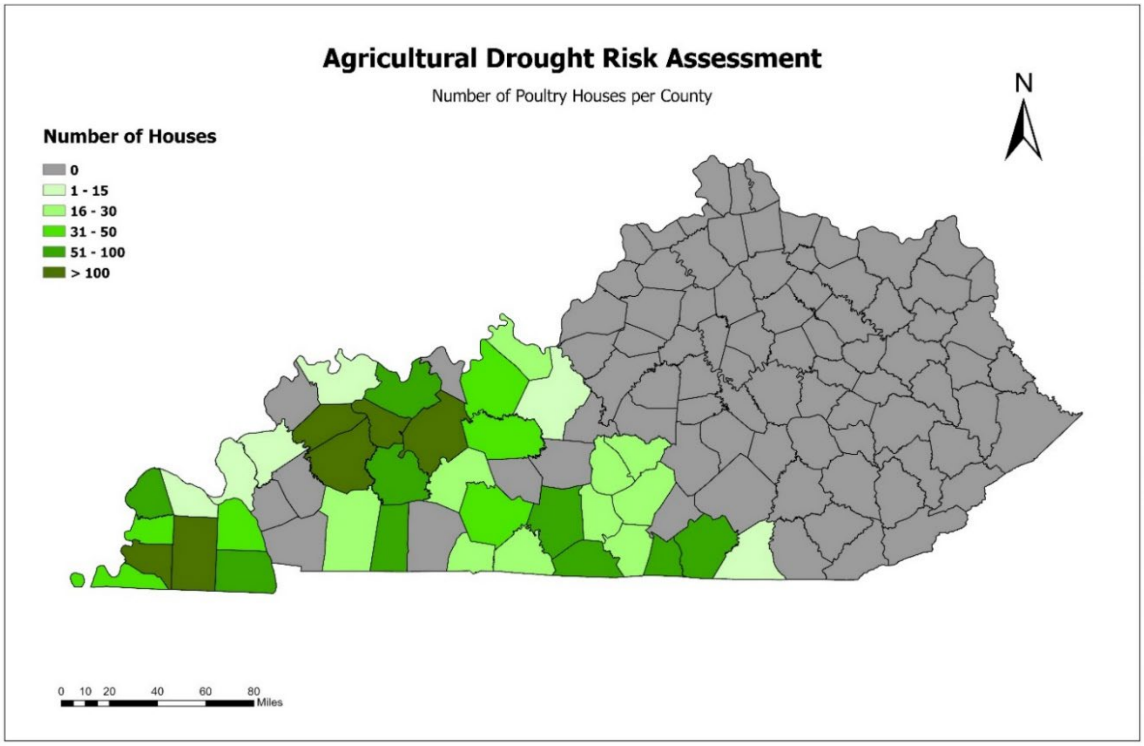


Figure 43. Number of Poultry Houses per County



Source: Kentucky Division of Water analysis of aerial imagery

Figure 44. Number of Poultry Houses per Water System

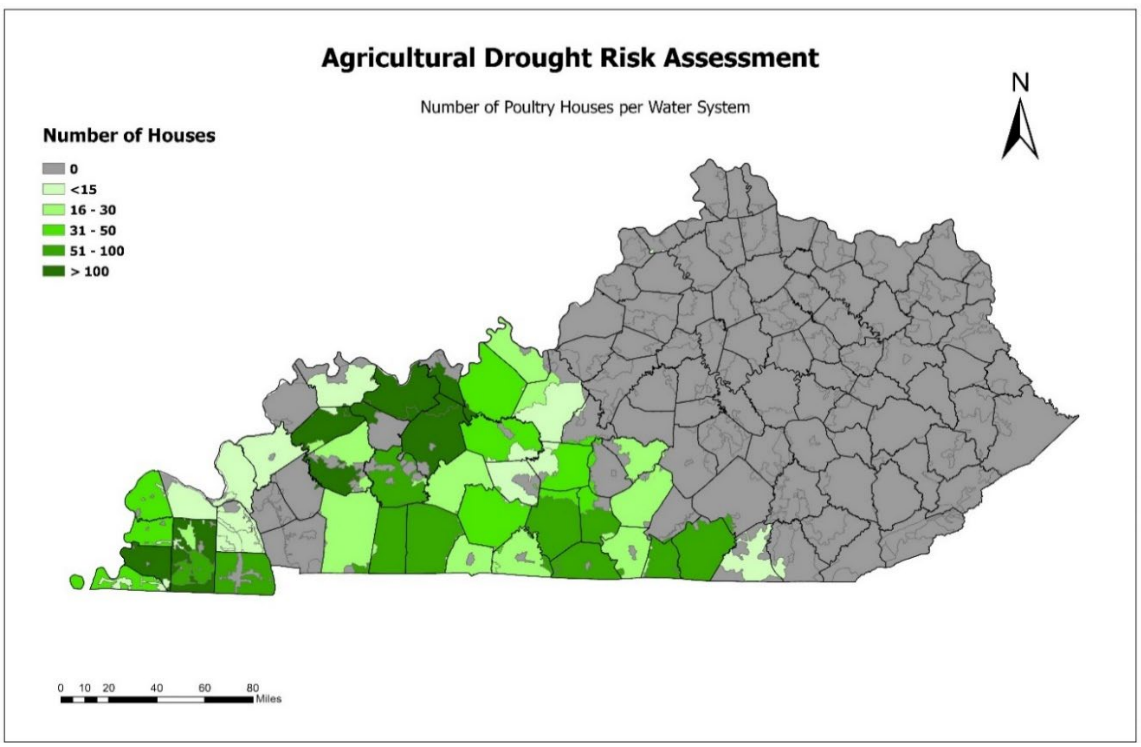


Figure 45. Number of Poultry Houses in a Moderate to Severe Hazard County

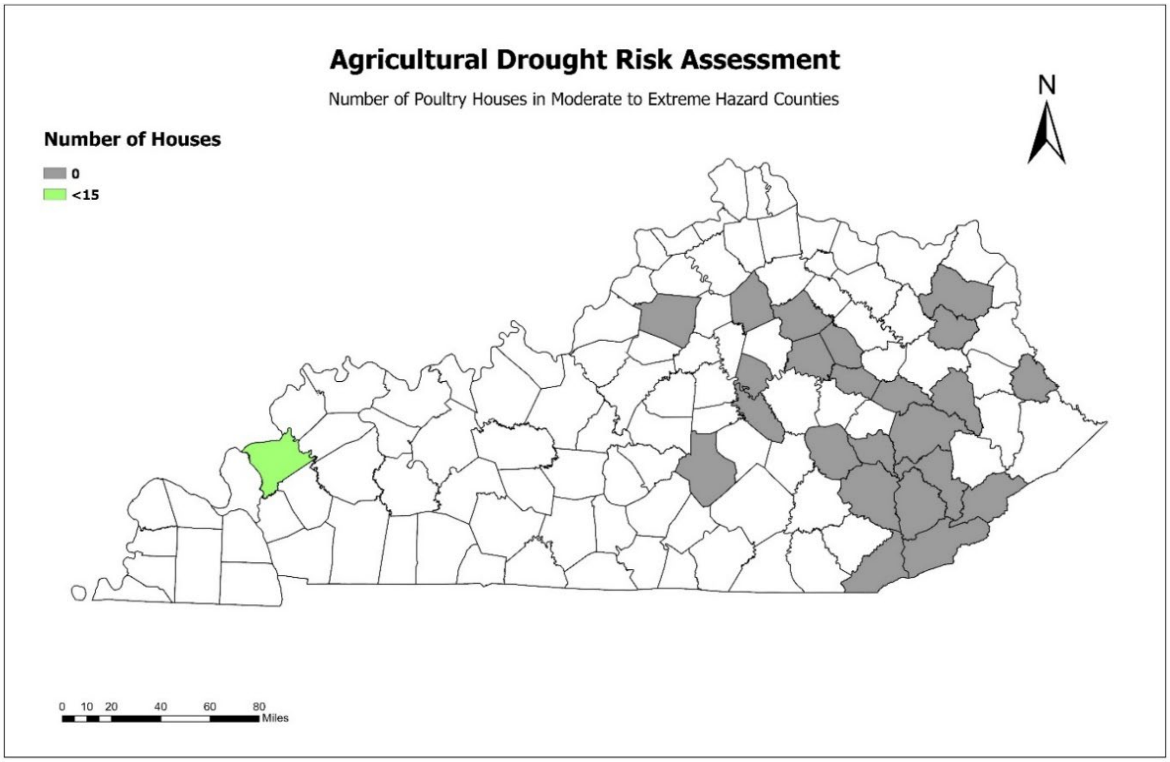


Figure 46. Number of Poultry Houses in a Moderate to Severe Hazard County

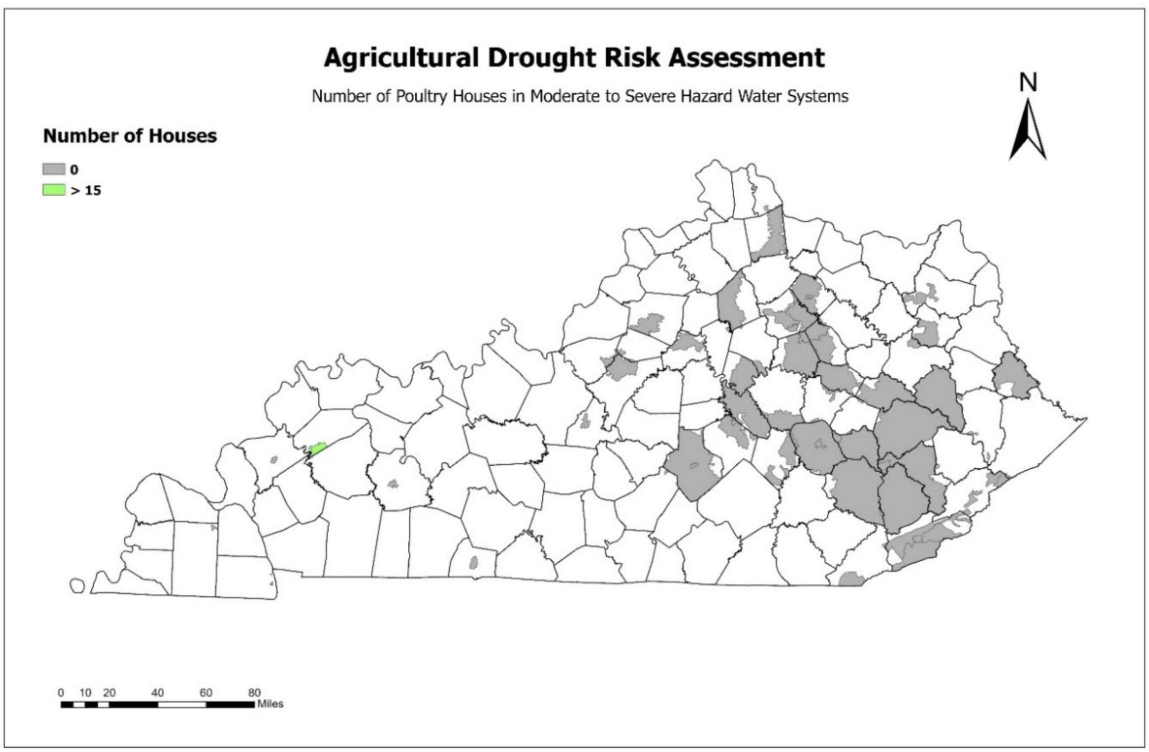
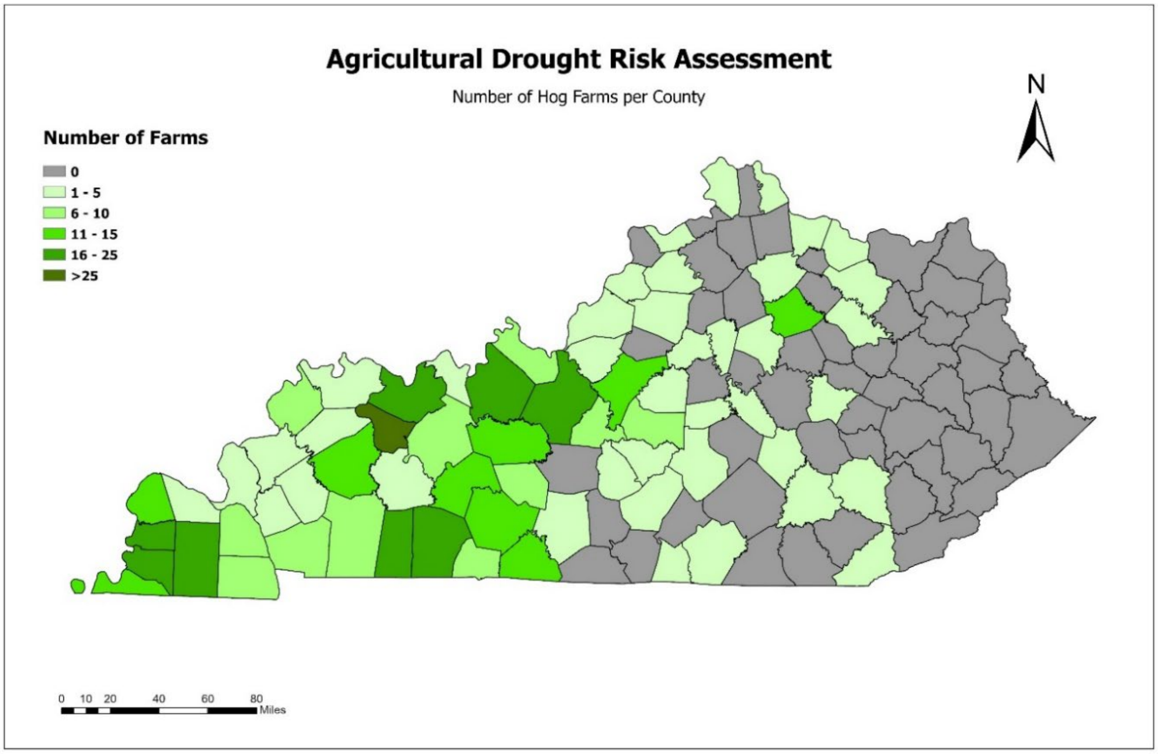


Figure 47. Number of Hog Farms per County



Source: Kentucky DEP database; KNDOP (No discharge operating permit) data

Figure 48. Number of Hog Farms per Water System

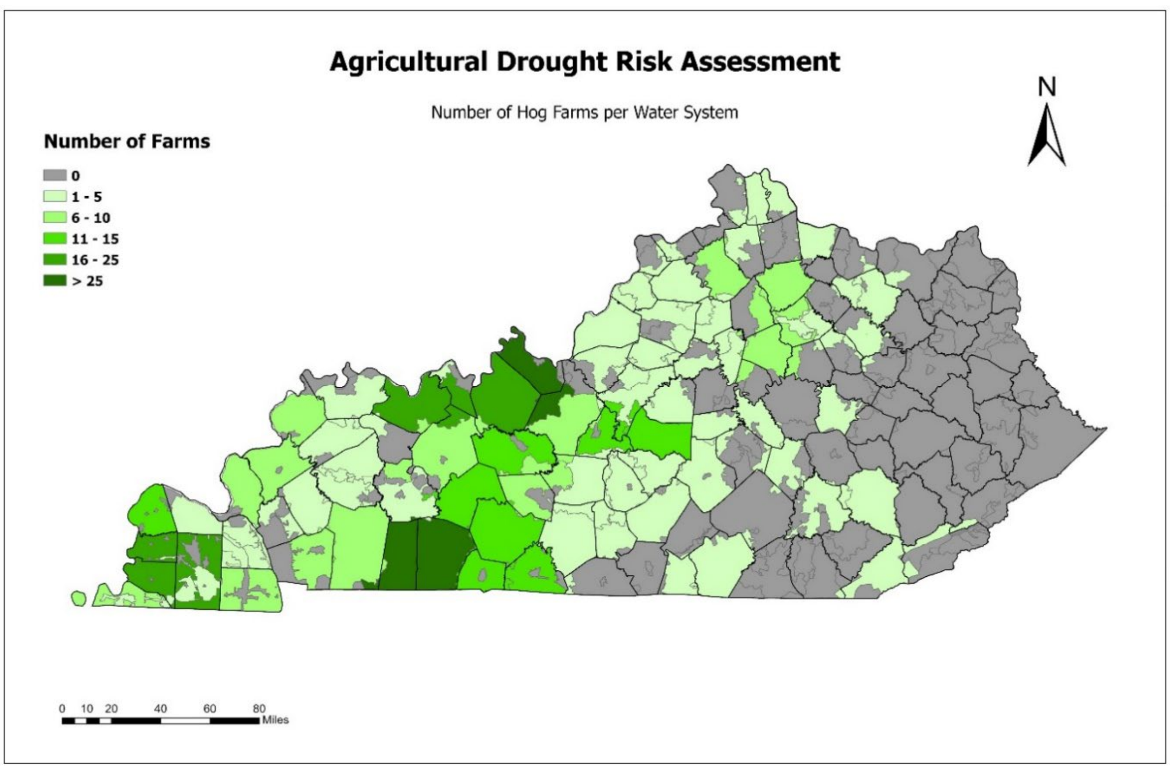


Figure 49. Number of Hog Farms in a Moderate to Severe Hazard County

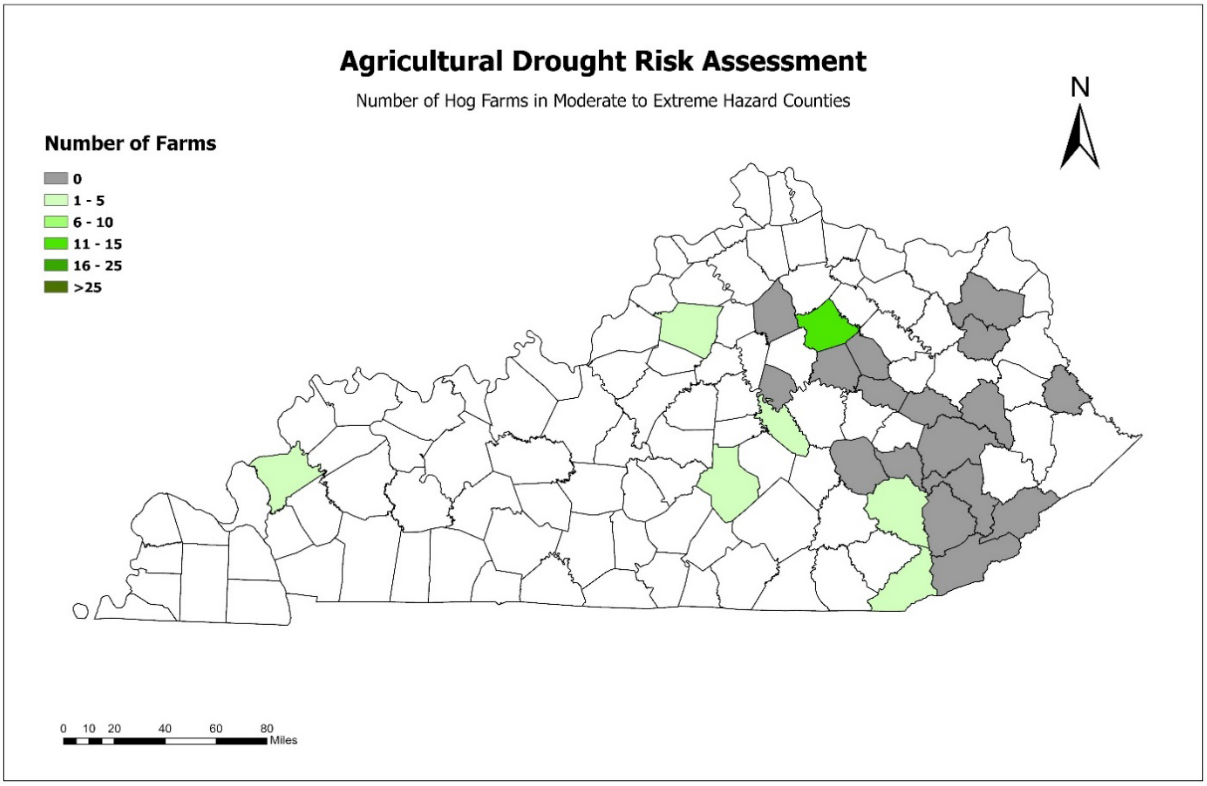
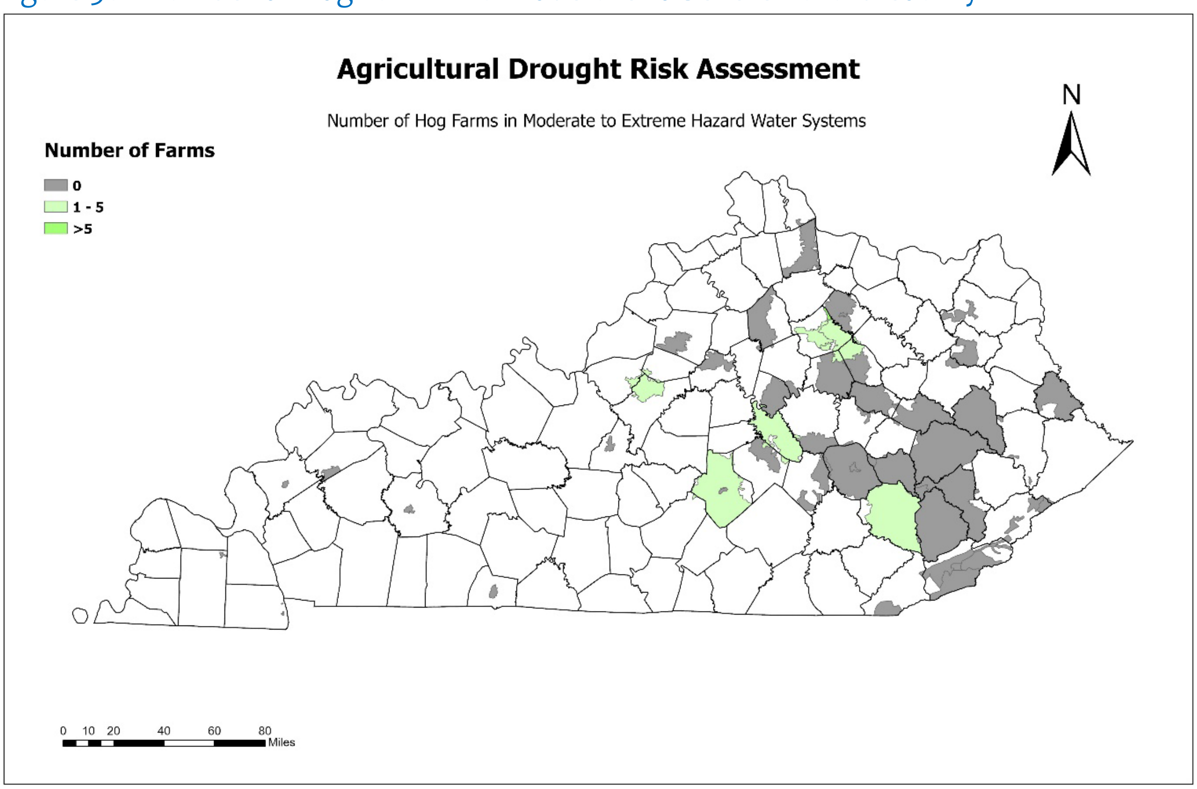


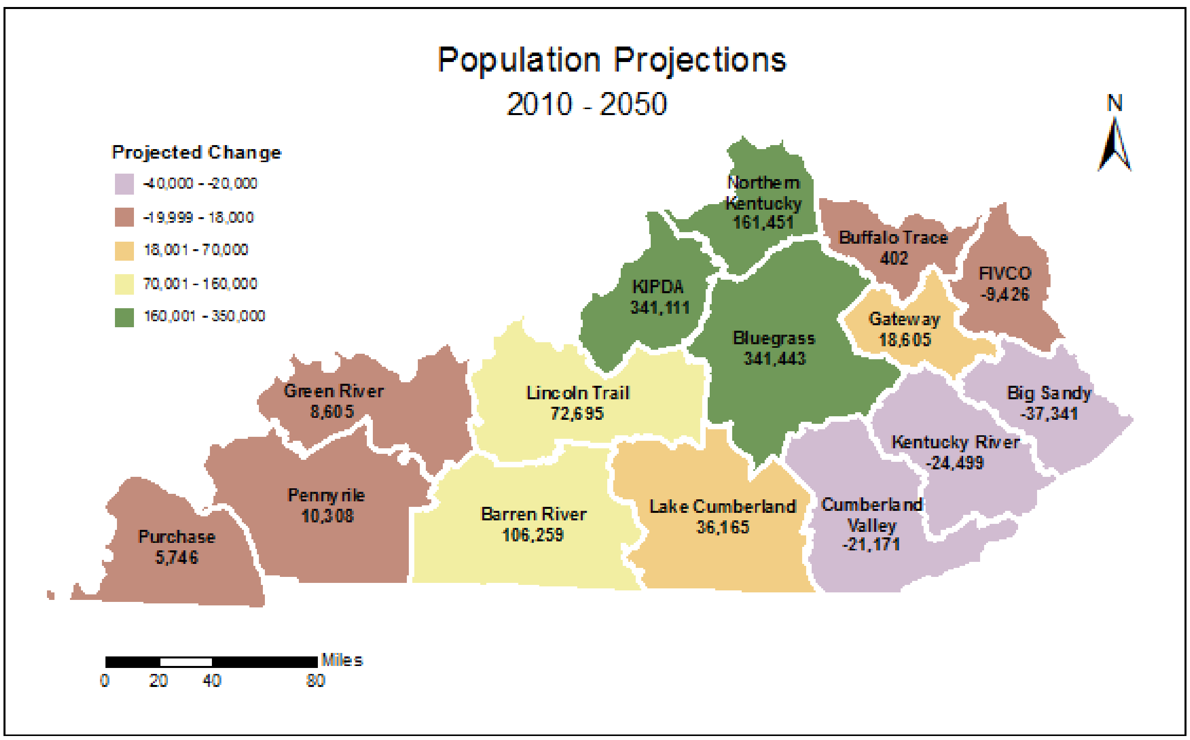
Figure 50. Number of Hog Farms in a Moderate to Severe Hazard County



Changes in Public Water Demand through 2050

Populations are estimated to change in Kentucky through 2050 as a result of emigration and attrition (death rates>birth rates) in the coal counties of eastern Kentucky, and a surge in immigration to the Louisville, Northern Kentucky and Bluegrass (Figure 51). From a risk perspective this change in the water supply landscape will likely reduce future water supply drought risks, assuming a simple straight-line estimate of water demand and population change (Table 10). The ADDs that are predicted to lose the most in population are also the ADDs with a majority of the moderate and high hazard public water systems. Conversely, areas that are predicted to grow in populations are predominantly in areas with Low or No Risk public water supplies and systems. Looking ahead, investment in eastern Kentucky infrastructure that coincides with diminishing populations may produce reductions in drought risk in the region.

Figure 9. Population Change Estimates 2010-2050 by Area Development District



Source: Kentucky State Data Center and Kentucky Cabinet for Education and Workforce Development

Table 84. Estimated Change in Kentucky Water Withdrawal for Public Water Supply through 2050

REGION	Total Water Withdrawal, 2015	Population, 2015	Per Capita Use	Population, 2050	Projected Total Water Withdrawn, 2050
	MGD		GPPD		MGD
KENTUCKY	**558**	**4,509,429**	**122**	**5,349,720**	**663**
Area Development Districts					
BarrenRiver	36	300,141	120	390,454	47
Big Sandy	18	151,480	119	116,752	14
Bluegrass	104	816,391	127	1,111,847	142
Buffalo Trace	6	57,508	104	56,880	6
Cumberland Valley	30	237,699	126	215,447	27
FIVCO	20	138,868	144	128,458	19
Gateway	11	84,781	130	100,257	13
Green River	30	217,407	138	222,077	31
Kentuckiana	143	1,008,643	142	1,300,202	184
Kentucky River	12	113,343	106	90,263	10
Lake Cumberland	24	214,745	112	243,421	27
Lincoln Trail	30	282,481	106	341,812	36
Northern KY	42	463,305	91	600,098	54
Pennyrile	32	223,324	143	229,613	33
Purchase	20	199,313	100	202,139	20

MGD = million gallons per day; GPPD = gallons per person per day
A majority of population increase projected in areas with low-risk water supplies as defined by this assessment.

Mitigation

Mitigation efforts to address drought have been ongoing since the mid 1980s when Kentucky developed its first water shortage response plan. In 2008 under direction of the state legislature the Division of Water formed the Kentucky Drought Mitigation Council and developed its first statewide drought response and mitigation plan. This plan created criteria for drought characterization as well as a communication network among multiple local, state and federal agencies. Perhaps most importantly, the plan outlined several categories of need to address long term mitigation efforts: many of these align with those of FEMA.

Table 95. Drought Mitigation

MITIGATION FOCUS AREAS	MITIGATION; PROGRAMS, PROJECTS AND FUNDING	COMMENTS	NUMBERS	NEEDS
Monitoring	Gages	1. Streamflow monitoring is needed on a real-time basis to identify drought severity and location. 2. Historical records of streamflow are critical for developing an understanding of the drought hazard 3. Streamflow records provide data for hydrologic assessments in several environmental permits and programs, including water availability for agriculture	Kentucky stream gage network is comprised of 227 real-time gages Kentucky Division of Water funds a subset of 47 gages at a cost of nearly $300,000 annually	Additional stream gages in smaller headwater areas of the major rivers basins
	Mesonet	1. Kentucky Mesonet data is used by numerous state, federal, local and private entities 2. Kentucky Mesonet data is the primary source for weather and climate data used for drought monitoring, water availability assessments and water withdrawal permitting	The Kentucky Mesonet provides professional grade weather data in nearly 80 of 120 counties.	Mesonet stations are needed in another 40 counties
	WWD data	1. The cabinet permits all water withdrawals over 10,000 gpd with exceptions for agriculture, oil and gas wells and domestic use. 2. The cabinet receives a daily record of withdrawals each month for each permitted water withdrawal 3. Water withdrawal reporting provides data needed for balancing water needs among permitted uses and other uses including agricultural and environmental demands	The Division of Water regulates approximately 700 water withdrawals totaling over 850 MGD through permitting and water withdrawal reporting	
	Groundwater Network	1. Groundwater is an important sure of supply for parts of Kentucky.	The Division of Water regulates 208 groundwater withdrawals totaling 210 MGD.	Development of a groundwater monitoring network in groundwater use areas

Planning	State Drought Plan	A state Drought Plan was created in 2008In 2008 under direction of the state legislature the Division of Water formed the Kentucky Drought Mitigation Council and developed its first statewide drought response and mitigation plan. This plan created criteria for drought characterization as well as a communication network among multiple local, state and federal agencies.		
	Local WSRP	Planning for and responding to water shortages at the local level is critical for adequate drought response. All water systems possess a water shortage response plan Water shortage response plans have not undergone a systematic update since the early 2000s.		Funding at the local level for improving and modernizing water shortage response plans
	WSP	Water supply planning regulations are currently under revision A new regulation will be focused on planning for growth, sustainability of water sources and infrastructure and providing service to a small number of unserved areas in Kentucky		Funding for updating water supply planning databases
Supply and Infrastructure Investment	Water Loss	Water loss is one of the biggest challenges facing water utilities In some instances water loss is a primary contributor to a water system drought vulnerability	Funding for repairing aging infrastructure Funding for improved leak detection and repair programs at the local level	
	Source	Many systems in Kentucky rely on drought vulnerable water sources In many cases a more reliable source is not available Interconnections or regional water suppliers can alleviate many of the remaining source issues in Kentucky	A case study from 1999 indicates that 39 water systems completely mitigated drought vulnerability through regionalization and new source development Nearly 300,000 customers and 35 MGD of demand were affected by regionalization and new source development	

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Craft, Kortney E., Mahmood, Rezaul, King, Stephen A., Goodrich, Gregory, Yan, Jun, 2013: *Drought and corn in Kentucky.* Applied Geography 45 (2013) 353e362

Palmer, W.C., 1965: *Meteorological Drought*. Research Paper No. 45, US Weather Bureau, Washington, DC.

Kentucky Energy and Environment Cabinet, Kentucky Drought Mitigation and Response Advisory Council, 2008: *Kentucky Drought Mitigation and Response Plan.* https://eec.ky.gov/Environmental-protection/Water/FloodDrought/Documents/KYDroughtMitigationAndResponsePlan.pdf

Appendix A. Soil Risk Assessment in Relation to Corn Yields

The percent of minimal to slight risk soils per county was corn yields in each county for 2010 and 2012 to validate the soil scoring process. Only the top crop producing counties, in terms of percent of acreage that was used to grow crops, were used. The 2010 drought was a mid to late summer moderate drought in western KY. The 2012 drought was an early to mid-summer extreme drought in western KY. Looking at both years, there is a good correlation between the percentage of minimal to slight risk soils and corn yields. Looking at yields at 2012 compared to 2010, you can see how much lower the yields are due to the severity of the drought. As mentioned in the results, the soil score is meant to show a soils vulnerability to a moderate drought. During more intense droughts, even crops in the most resilient soil will be significantly impacted.

Figure 52. Comparison of corn yields and percent of minimal to slight risk soils per county in 2010

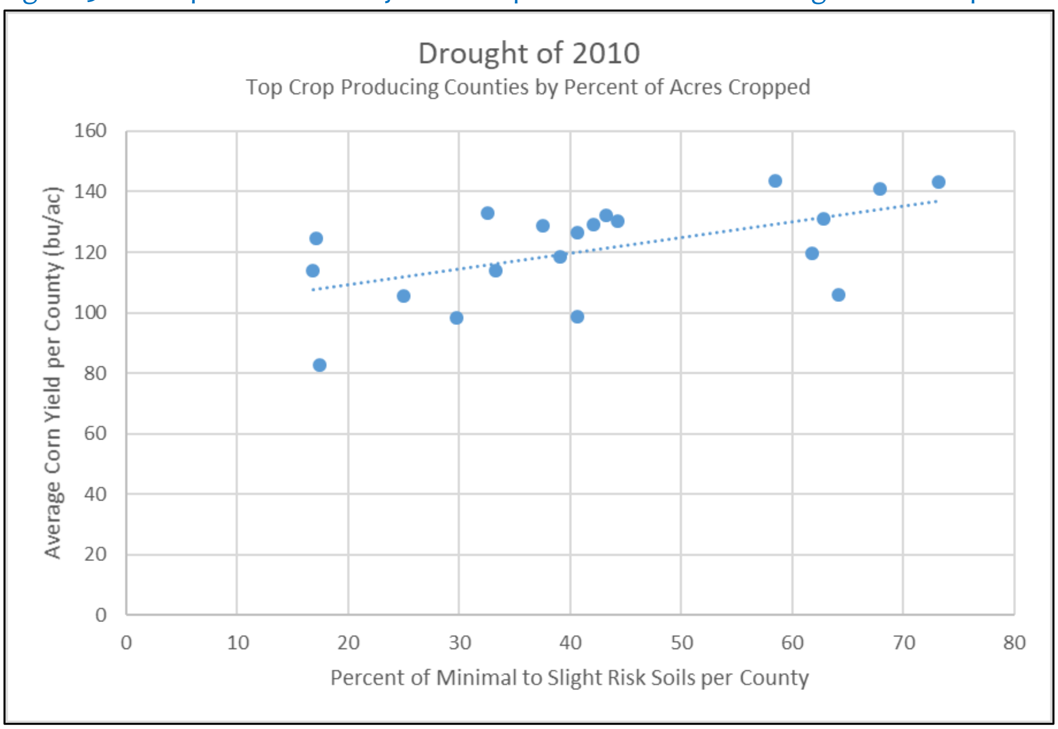
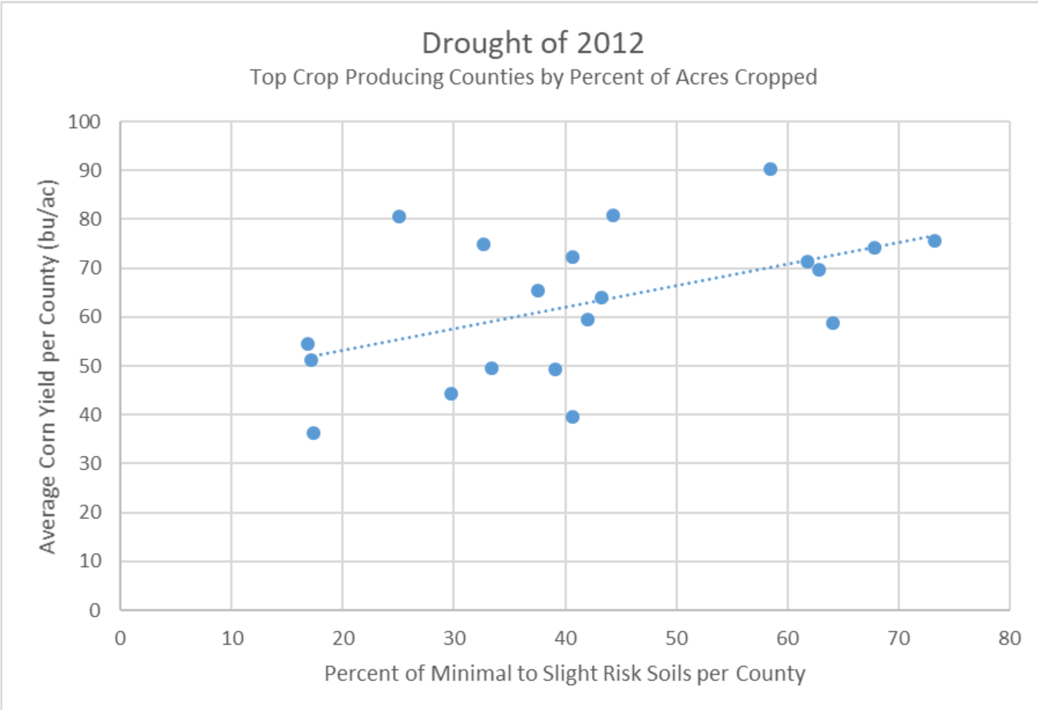


Figure 53. Comparison of corn yields and percent of minimal to slight risk soils per county in 2012



Potential Impacts from Drought to Community Lifelines

Community Lifeline	Level of Impact	Description of Impacts	Area of Impact
Communications	Low	No significant effects to the Communications lifeline are expected.	Regional
Energy	Low	Hydroelectric power generation could witness challenges resulting from water resource reduction. Severe and/or especially prolonged drought may result in structural stresses to infrastructure	Regional
Food, Water, Shelter	High	The food supply could be greatly reduced and the resulting supply chain could be truncated: Agricultural crop production will be reduced. Food and water resources will be reduced locally and, subsequently, regionally. Economic impacts to agricultural interests resulting from lower productivity and increased costs, including irrigation.	Regional
Hazardous Materials	Low	No significant effects to the Hazardous Materials lifeline are expected.	Regional
Health and Medical	Medium	Reduced availability of water could have negative health effects on people and animals. A shortage in water resources could negatively impact emergency and medical operations	Regional
Safety and Security	Low	During severe and prolonged drought and assuming political mismanagement and poor prioritization of water resources, a shortage in availability or consistency in water may compromise firefighting capabilities.	Regional
Transportation	Low	No significant effects to the Transportation lifeline are expected. Severe and/or prolonged drought may result in structural stresses to transportation infrastructure.	Localized; Regional

Drought

Probability

The following narrative is in response to revisions required for approval of Kentucky's state hazard mitigation plan under the interpretation of 44 CFR §201.4 used during 2023: The probability of drought occurrence had to be discussed overtly in five (5) different ways: By range of anticipated intensities, by frequency, by duration, by location, and by incorporating climate change assumptions.

Previously, this hazard identification and risk assessment (HIRA) for drought to accompany the 2023 update to Kentucky's hazard mitigation plan discussed the probability for future drought occurrence as follows:

"…[T]here have been 28 moderate droughts since 1895 with 23 progressing to at least severe drought. There have been 12 regional droughts and 11 statewide droughts. On average, Kentucky has experienced a severe drought at least once every 5-6 years. Severe regional droughts are occurring in some area of Kentucky about once every 10 years, and statewide droughts have recurred on an 11-year interval.

"Most droughts that have reached the moderate threshold (28) advanced to at least severe drought (23). Thus, the PDSI [Palmer Drought Severity Index] has some utility in drought monitoring as a longer-term signal that hydrologic drought may be developing.

"…[M]onthly PDSI values were evaluated to calculate a three-month running average, the length of a 'typical' irrigation season…Recurrence intervals and percent chances for each PDSI threshold were calculated from a Weibull plotting position. Based on this data, on average Kentucky experiences moderate to slightly severe drought about every five [5] years, moderate to somewhat extreme [drought] every 10 years, and extreme drought at least every 20 years. The data also suggest there is a 17-24% chance of a severe drought and a 7-11% chance of extreme drought each year, respectively (Division of Water, 2023, pp. D-DOW 18 – D-DOW 19)."

Additionally, "…a majority of droughts progress to severe or worse once the threshold for moderate drought is reached (Division of Water, 2023, p. D-DOW 20)."

"Moderate," "Severe," and "Extreme" drought are references to the Palmer Drought Severity Index (PDSI): "…'Moderate' drought is reached when at least three (3) consecutive months fall below a PDSI value of -2.00. Drought is considered to persist until the PDSI is once again in a normal (at least zero) range. 'Severe' drought is indicated when PDSI reaches -3.00 and 'Extreme' drought is indicated when PDSI falls below -4.00 (Division of Water, 2023, p. D-DOW 11)."

Probability x Range of Anticipated Intensities and Frequency

Thus, in terms of a range of anticipated intensities and frequency, the above is restated as follows:

Referencing the PDSI, Kentucky projects that it will experience “moderate” drought at least once every five (5) years. As it is analyzed here that “severe” and “extreme” drought conditions require an establishment of “moderate” drought conditions first, Kentucky projects that it will experience “moderate” drought conditions that lead to the low end of the PDSI range defining “severe” drought conditions once very five (5) years. Kentucky projects that it will experience “moderate” drought conditions that lead inarguably to “severe” drought conditions once every 10 years. Kentucky projects that it will experience “moderate” drought conditions that lead to “extreme” drought conditions once every 20 years. Kentucky projects a 17%-24% probability of suffering a “severe” drought event each year. Kentucky projects a 7%-11% probability of suffering an “extreme” drought event each year.

Probability x Duration

In terms of duration, the previous probability statements apply. The following clarifying language is added to each of the statements (highlighted in bold):

Referencing the PDSI, Kentucky projects that it will experience “moderate” drought at least once every five (5) years. As it is analyzed here that “severe” and “extreme” drought conditions require an establishment of “moderate” drought conditions first, Kentucky projects that it will experience “moderate” drought conditions that lead to the low end of the PDSI range defining “severe” drought conditions **that persist three (3) months or longer** once very five (5) years. Kentucky projects that it will experience “moderate” drought conditions that lead inarguably to “severe” drought conditions **that persist for three (3) months or longer** once every 10 years. Kentucky projects that it will experience “moderate” drought conditions that lead to “extreme” drought conditions **that persist for three (3) months or longer** once every 20 years. Kentucky projects a 17%-24% probability of suffering a “severe” drought event **that persists for three (3) months or longer** each year. Kentucky projects a 7%-11% probability of suffering an “extreme” drought event **that persists for three (3) months or longer** each year.

In terms of location, the following observation using the NCEI Storm Events data is added to the previous probability statements in order both to satisfy the explicit requirement that probability be differentiated by location and to set the basis for a data limitation discussed in the drought risk assessment and clarified here: Using only NCEI Storm Events data, there seems a considerably higher probability of the previously mentioned probabilities for future drought events occurring in counties and cities comprising “western” Kentucky. Conversely, there is considerably lower probability of the previously mentioned probabilities for future drought events occurring for the counties and cities comprising “eastern” Kentucky. This statement is justified by viewing the National Centers for Environmental Information (NCEI) and its Storm Events database records for drought events for all Kentucky from the beginning of the period-of-record (1996) until its current ending: The Boyd County “zone” (i.e., Boyd County and counties and cities surrounding it as defined by the National Weather Service) is the only set of jurisdictions in “eastern” Kentucky to have experienced drought as officially recorded through the National Weather Service. All other instances of drought recorded occurred for the counties cities comprising “western” Kentucky.

The NCEI Storm Events database supplies a record of National Weather Service designations as they apply to forecasting events for the nation’s jurisdictions and as records of natural hazard events’ monetary damages and effects on human lives, again, by jurisdiction. Regarding drought, “[f]or nearly two decades, the National Weather Service (NWS) has issued Drought Information Statements to provide up-to-date reports on the current drought situation for regional Weather Forecast Offices’ warning and forecast area. These timely statements summarize recent weather and hydrologic conditions, discuss drought impacts, and provide a local drought outlook.”[1] “Storm Data is provided by the National Weather Service (NWS) and contain statistics on personal injuries and damage estimates. Storm Data covers the United States of America. The data began as early as 1950 through to the present, updated monthly with up to a 120-day delay possible. NCDC[2] [NCEI] Storm Event database allows users to find various types of storms recorded by county, or use other selection criteria as desired. The data contain a chronological listing, by state, of hurricanes, tornadoes, thunderstorms, hail, floods, drought conditions, lightning, high winds, snow, temperature extremes, and other weather phenomena.”[3]

[1] See: NOAA/NIDIS. (April 16, 2024). “National Weather Service Drought Information Statements Provide Improved Drought Messaging.” Drought.gov National Integrated Drought Information System News and Events. https://www.drought.gov/news/national-weather-service-drought-information-statements-provide-improved-drought-messaging.
[2] The National Center for Environmental Information (NCEI) used to be called the National Climatic Data Center (NCDC).
[3] See: Data.gov. (September 19, 2023). “Data Catalog ~ Organizations: NCDC Storm Events Database.” https://catalog.data.gov/dataset/ncdc-storm-events-database2.

This difference in location is undermined through closer examination and a broader use of data sources: Kentucky's Division of Water (DOW) and its Drought Monitoring Coordinator clarify and correct that there is little variation in the previously mentioned probabilities for future drought events across the commonwealth. The climate of Kentucky is such that one would expect similar drought vulnerabilities regardless of location. Historical data from both the Palmer Drought Severity Index and the U.S. Drought Monitor confirms that the probability of future drought occurring across Kentucky is equal across the state.

Kentucky's Division of Water (DOW) clarifies that drought is unique among natural disasters as it is not a distinct event like a flood or tornado that has a discrete beginning and end. It is a long-lasting event, lasting months, years, and even decades. Its impacts are widespread and include (but are not limited to) water shortages, decreased crop yields or loss, livestock stress, increased wildfire activity, shifting ground damaging foundations and waterlines, fish kills, ecological stress, and tree stress. Some impacts, such as wildlife and tress stress and groundwater shortages, may not be apparent until the following year, if not longer.

Because of this, using databases such as the NCEI Storm Events database can be unreliable: It does capture fully the damages created by drought. The NCEI Storm Events database only captures crop losses that are reported to it. The data only represents areas where large amounts of row crops are grown. Row crops are disproportionately grown in Kentucky within its "western" designation implying that drought events and their damages are over-represented in Kentucky's "west" and under-represented in Kentucky's "east." "Eastern" Kentucky has some of the most vulnerable drinking water systems in the commonwealth.

As an example of "under-reporting" for "eastern" Kentucky, during the 2008 drought, the City of Salyersville (in Magoffin County) had to ration water due to the loss of flow in the Licking River. Additionally, there have been drought-related water shortages and concerns over the past 15 years concerning systems in Harlan, Letcher, Clay, Wolfe, Carter, and Martin counties. Drought conditions in 1999 and 2016 resulted in widespread wildfire issues throughout "eastern" Kentucky.

Kentucky’s Division of Water (DOW) developed the 2023 Kentucky Enhanced Hazard Mitigation Plan drought risk assessment. It focused on identifying agricultural drought using both data and scientific methods. A data limitation raised in the risk assessment concerns the reliance by the National Risk Index on crop insurance indemnity payments: The drought risk assessment provided an illustration of crop insurance indemnity payments by county and the percentage of those payments made specifically for drought in order to raise the following issue: These payments were highest in the western Mississippi Plateau and lowest in “eastern” Kentucky. But, crop indemnity payments is an indication neither of where drought was prevalent nor where it was severe. It is just a map of where the most crops are grown. It does not account for pasture lands and livestock; it does not account for small plots of row crops and family gardens, i.e., conditions that are prevalent in “eastern” Kentucky.

Figure 1. is presented below in order to illustrate the number of times each county within Kentucky has been eligible for USDA Farm Service Agency (FSA) Livestock Forage Disaster Program payments. This figure demonstrates that such payments have been distributed across the entire commonwealth and were not concentrated only in “western” Kentucky.

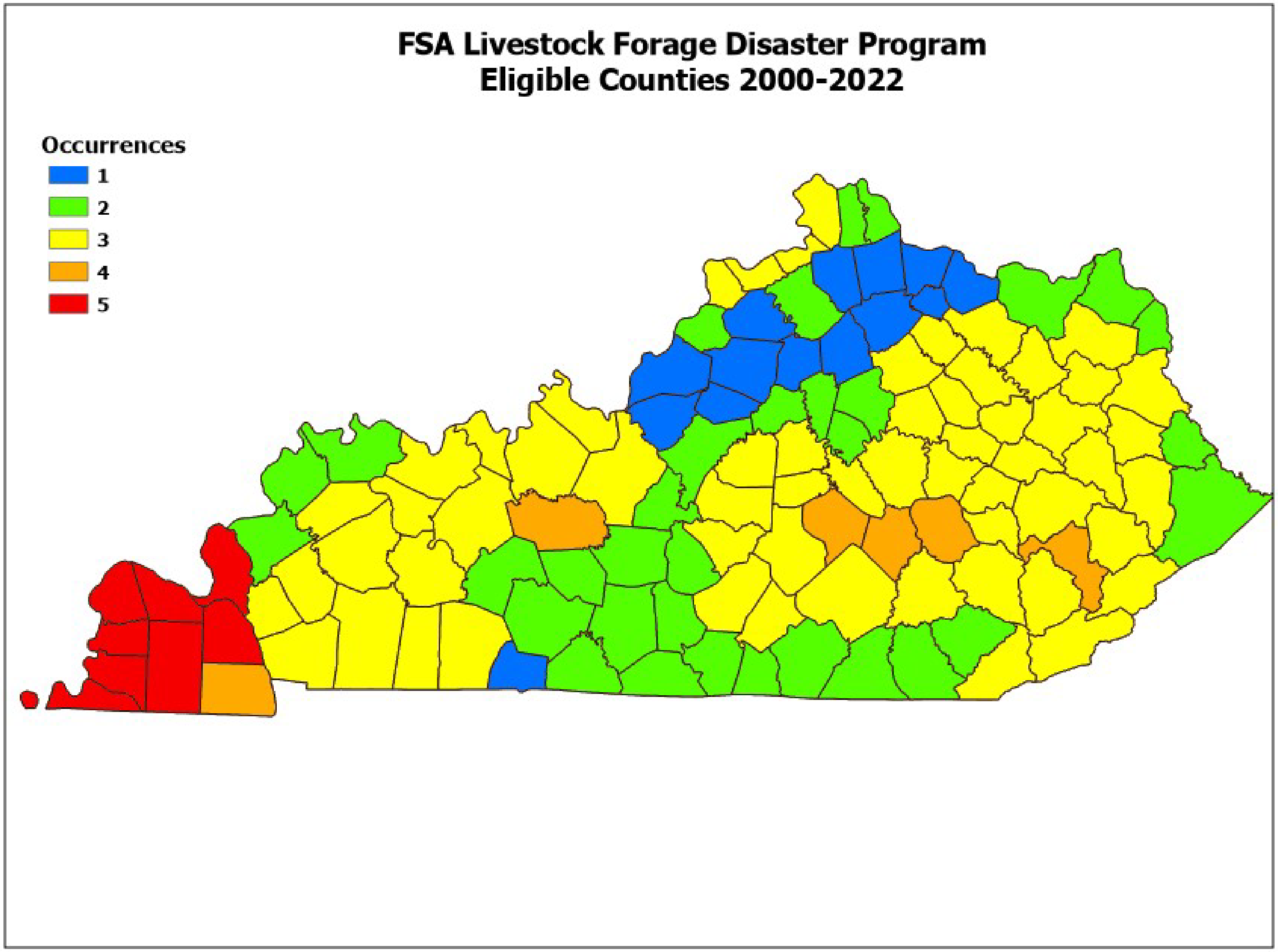


Figure 1: Map showing the number of times livestock and forage producers have been eligible for FSA Livestock Forage Disaster Program payments due to drought from 2000-2022.

Table 5. in the 2023 Kentucky Enhanced Hazard Mitigation Plan's drought risk assessment was developed by Kentucky's Division of Water in order to analyze and show recurrence intervals for drought based on climate divisions. The recurrence interval of "moderate" drought for the Western Climatic Division (CD-1) and the Eastern Climatic Division (CD-4) is the same: 6.1 years.

Below, Figure 2. is added to the 2023 Kentucky Enhanced Hazard Mitigation Plan to illustrate the distribution of drought across the commonwealth. It shows that there have been numerous drought conditions in "eastern" Kentucky. There is a slight decrease in drought occurrence from south to north; but, this is not significant. Overall, there is no variation for drought across Kentucky.

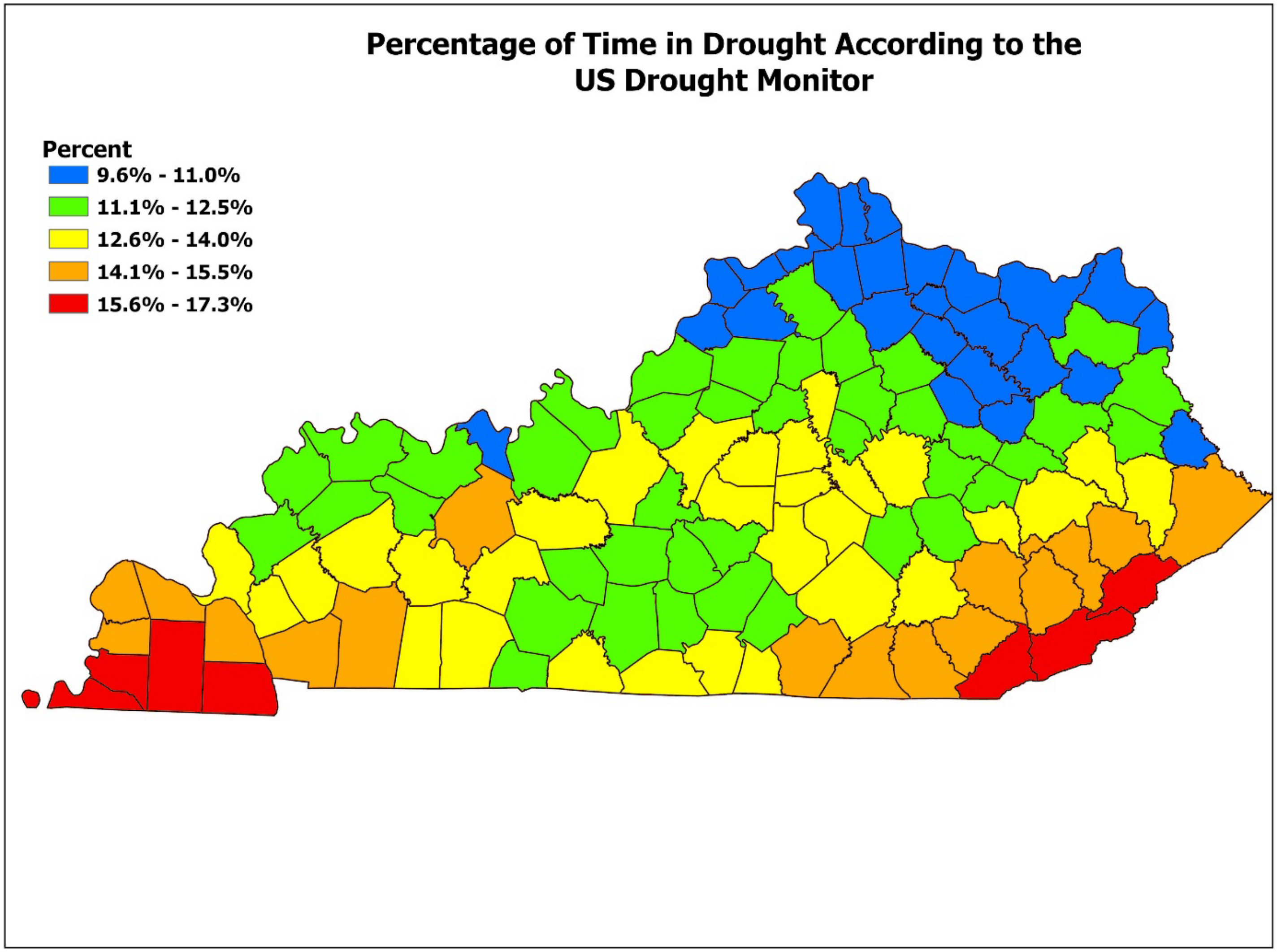


Figure 2: Map showing the percentage of time a particular county has been in at least Moderate Drought (D1) according to the US Drought Monitor.

Probability x Climate Change

"Climate change has…altered the natural pattern of droughts, making them more frequent, longer, and more severe (USGS)[4]."

The aforementioned probability estimates include considerations of climate change effects: The probability estimates were validated against data and observations from the years between 1930 and the late 1950s that were highly drought-prone and produced multi-year droughts that persisted for atypically longer periods of time. It is the environment of these years in between 1930 and the 1950s toward which climate change is leading Kentucky. So, that probability estimates include the possibility of an environment like that of the years spanning 1930 to the 1950s implies that the probability estimates include climate change effects.

[4] See: U.S. Geological Survey. (n.d.) "Droughts and Climate Change." https://www.usgs.gov/science/science-explorer/climate/droughts-and-climate-change#overview.