Risk Assessment:
Extreme Temperatures

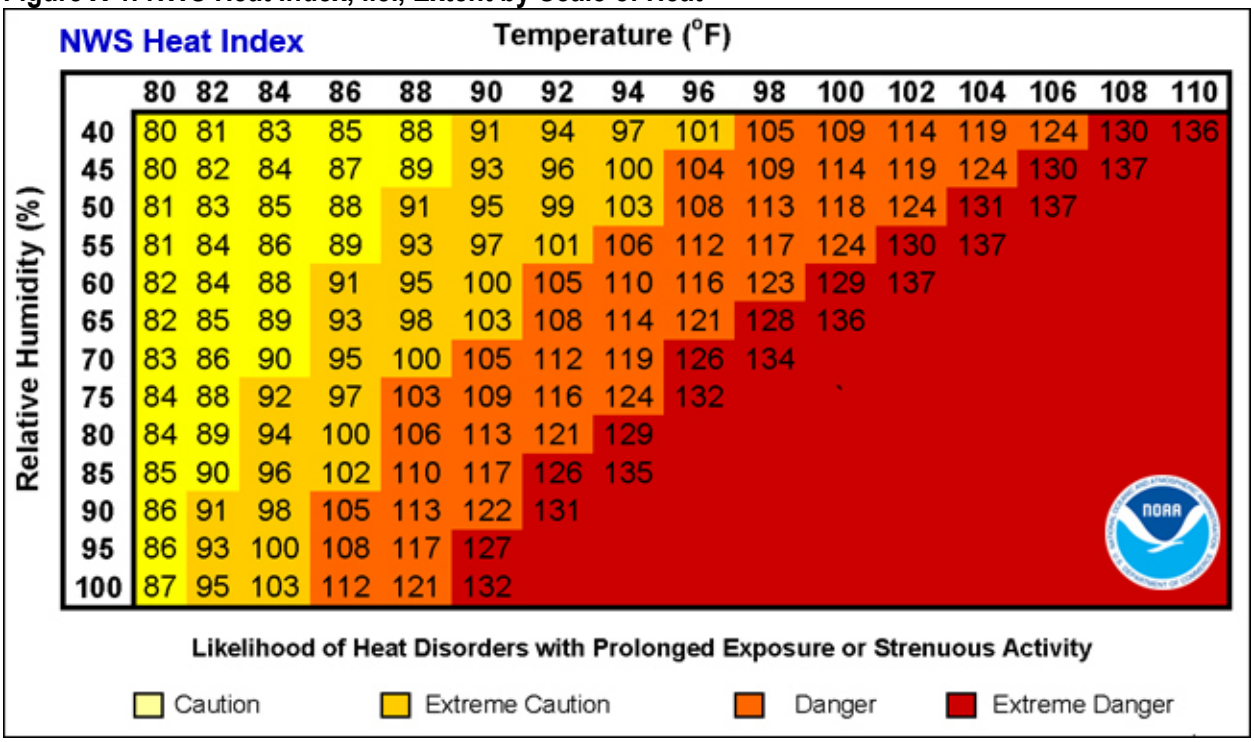
By: University of Kentucky Hazard Mitigation Grants Program Office (UK-HMGP)
With: National Weather Service (NWS)

Types and Extent

This analysis relies on National Weather Service (NWS) recommendations with additional analysis by the University of Kentucky Hazard Mitigation Grants Program Office (UK-HMGP). The types of Extreme Temperatures are the definitions used in the warnings NWS provides for this hazard type.

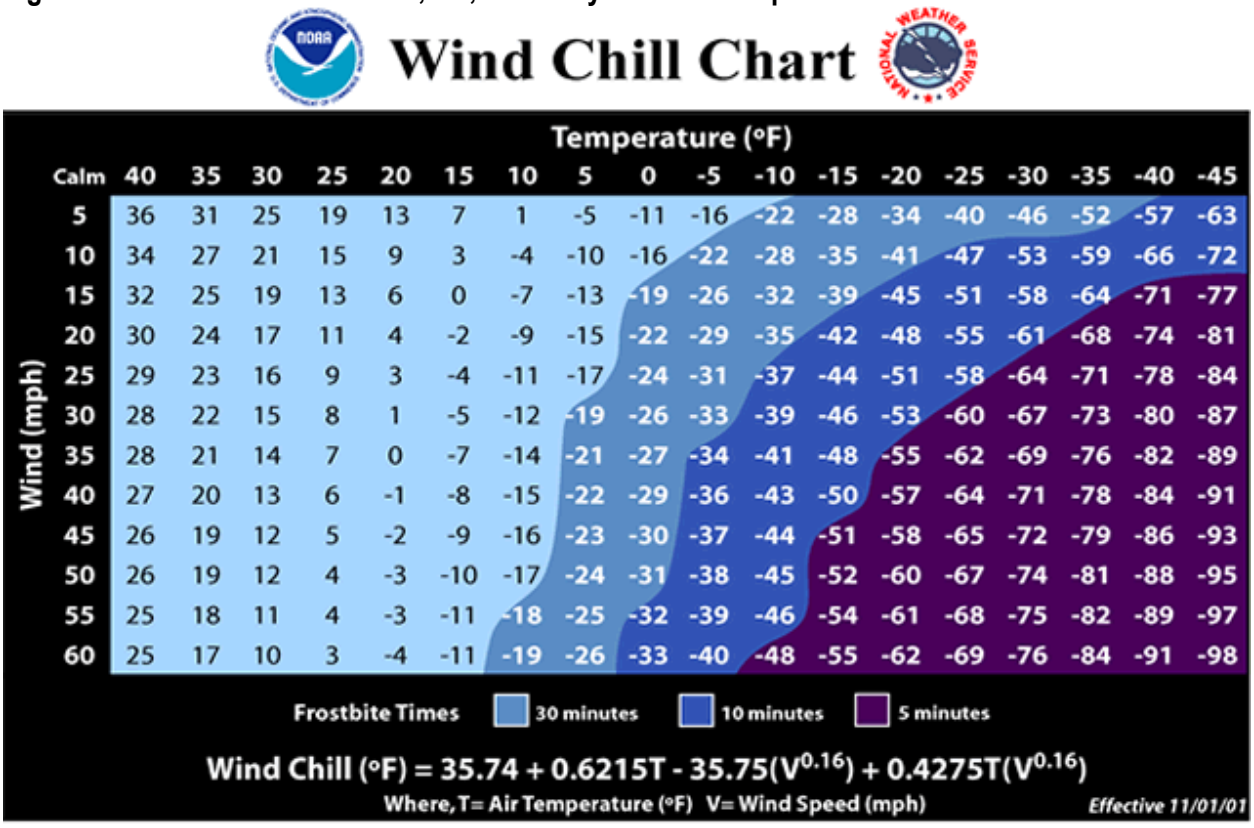
Excessive Heat: Criteria for "Excessive Heat" and its subsequent Warning by the National Weather Service (NWS) is a heat index of 105° F or greater that will last for two (2) hours or more.

Figure X-1. NWS Heat Index, i.e., Extent by Scale of Heat



Extreme Cold/Wind Chill: The definition of "Extreme Cold" by the National Weather Service is variable depending upon the region of the country in which one resides: "What constitutes extreme cold varies in different parts of the country. In the southern U.S., near freezing temperatures are considered extreme cold. Freezing temperatures can cause severe damage to citrus fruit crops and other vegetation. Pipes may freeze and burst in homes that are poorly insulated or without heat. …[I]n the north, extreme cold means temperatures well below zero[1]." So, rather than issue a Warning for Extreme Cold, NWS ultimately issues a warning for Wind Chill. A Wind Chill Warning still is relative to the area of the country within which the Warning is issued: "NWS issues a wind chill warning when dangerously cold wind chill values are expected or occurring. [For those] in an area with a wind chill warning, [they should] avoid going outside during the coldest parts of the day…[2]" However, Wind Chills do produce a danger for frostbite that is not relative to one region of the U.S. over another: Five (5) degrees Fahrenheit with 30 mile-per-hour winds produces a wind chill that makes the temperature feel like 19 degrees below zero Fahrenheit. Nineteen degrees below zero Fahrenheit can produce frostbite within 30 minutes.

Figure X-2. NWS Wind Chill Chart, i.e., Extent by Scale of Temperature and Wind



[1] See National Weather Service. "Stay Safe in the Extreme Cold." https://www.weather.gov/dlh/extremecold. [Last accessed October 23, 2018].
[2] See National Weather Service. "Wind Chill Warning vs. Watch." https://www.weather.gov/safety/cold-wind-chill-warning. [Last accessed October 23, 2018].

Previous Occurrences, Locations, and Impacts

During its 2013-2018 mitigation planning cycle, Kentucky experienced the following Excessive Heat and Extreme Cold/Wind Chill events. Per multiple meetings with Kentucky branches of the National Weather Service (NWS), the National Oceanic and Atmospheric Administration's (NOAA's) National Centers for Environmental Information's (NCEI's) Storm Events Database represents best available data for locations, previous occurrences, and impacts resulting from Excessive Heat and Extreme Cold/Wind Chill.

As a note on formatting, NCEI's Storm Events Database treats Excessive Heat and Extreme Cold/Wind Chill events as individual to each county affected when, in fact, the event was one event that affected multiple counties. For example, between 1/6/2014 and 2/19/2015, there were four (4) Extreme Cold/Wind Chill events affecting anywhere from four (4) to 14 counties. NCEI records 26 records, however: One record for each county affected by the one of four (4) events.

Table X-1. Previous Occurrence, Impacts, Locations of Excessive Heat Events, 2013-2018

Location	County/Zone	St.	Date	Time	T.Z.	Type	Mag	Dth	Inj	PrD[3]	CrD[4]
Totals:								0	0	0.00K	0.00K
MUHLENBERG (ZONE)	MUHLENBERG (ZONE)	KY	07/27/2015	12:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
WEBSTER (ZONE)	WEBSTER (ZONE)	KY	07/27/2015	12:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
UNION (ZONE)	UNION (ZONE)	KY	07/27/2015	12:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
TRIGG (ZONE)	TRIGG (ZONE)	KY	07/27/2015	12:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
TODD (ZONE)	TODD (ZONE)	KY	07/27/2015	12:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
MCLEAN (ZONE)	MCLEAN (ZONE)	KY	07/27/2015	12:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
MCCRACKEN (ZONE)	MCCRACKEN (ZONE)	KY	07/27/2015	12:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
MARSHALL (ZONE)	MARSHALL (ZONE)	KY	07/27/2015	12:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
LYON (ZONE)	LYON (ZONE)	KY	07/27/2015	12:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
LIVINGSTON (ZONE)	LIVINGSTON (ZONE)	KY	07/27/2015	12:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
HOPKINS (ZONE)	HOPKINS (ZONE)	KY	07/27/2015	12:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
HICKMAN (ZONE)	HICKMAN (ZONE)	KY	07/27/2015	12:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
HENDERSON (ZONE)	HENDERSON (ZONE)	KY	07/27/2015	12:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
GRAVES (ZONE)	GRAVES (ZONE)	KY	07/27/2015	12:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
FULTON (ZONE)	FULTON (ZONE)	KY	07/27/2015	12:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
DAVIESS (ZONE)	DAVIESS (ZONE)	KY	07/27/2015	12:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
CRITTENDEN (ZONE)	CRITTENDEN (ZONE)	KY	07/27/2015	12:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
CHRISTIAN (ZONE)	CHRISTIAN (ZONE)	KY	07/27/2015	12:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
CARLISLE (ZONE)	CARLISLE (ZONE)	KY	07/27/2015	12:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
CALLOWAY (ZONE)	CALLOWAY (ZONE)	KY	07/27/2015	12:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
CALDWELL (ZONE)	CALDWELL (ZONE)	KY	07/27/2015	12:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
BALLARD (ZONE)	BALLARD (ZONE)	KY	07/27/2015	12:00	CST-6	Excessive Heat		0	0	0.00K	0.00K

[3] "PrD" refers to value of Property Damage reported to National Weather Service.
[4] "CrD" refers to value of Crop Damage reported to National Weather Service.

Location	County/Zone	St.	Date	Time	T.Z.	Type	Mag	Dth	Inj	PrD[3]	CrD[4]
BALLARD (ZONE)	BALLARD (ZONE)	KY	07/21/2017	11:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
CALDWELL (ZONE)	CALDWELL (ZONE)	KY	07/21/2017	11:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
CALLOWAY (ZONE)	CALLOWAY (ZONE)	KY	07/21/2017	11:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
CARLISLE (ZONE)	CARLISLE (ZONE)	KY	07/21/2017	11:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
CHRISTIAN (ZONE)	CHRISTIAN (ZONE)	KY	07/21/2017	11:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
CRITTENDEN (ZONE)	CRITTENDEN (ZONE)	KY	07/21/2017	11:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
DAVIESS (ZONE)	DAVIESS (ZONE)	KY	07/21/2017	11:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
FULTON (ZONE)	FULTON (ZONE)	KY	07/21/2017	11:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
GRAVES (ZONE)	GRAVES (ZONE)	KY	07/21/2017	11:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
HENDERSON (ZONE)	HENDERSON (ZONE)	KY	07/21/2017	11:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
HICKMAN (ZONE)	HICKMAN (ZONE)	KY	07/21/2017	11:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
HOPKINS (ZONE)	HOPKINS (ZONE)	KY	07/21/2017	11:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
LIVINGSTON (ZONE)	LIVINGSTON (ZONE)	KY	07/21/2017	11:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
LYON (ZONE)	LYON (ZONE)	KY	07/21/2017	11:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
MARSHALL (ZONE)	MARSHALL (ZONE)	KY	07/21/2017	11:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
MCCRACKEN (ZONE)	MCCRACKEN (ZONE)	KY	07/21/2017	11:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
MCLEAN (ZONE)	MCLEAN (ZONE)	KY	07/21/2017	11:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
MUHLENBERG (ZONE)	MUHLENBERG (ZONE)	KY	07/21/2017	11:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
TODD (ZONE)	TODD (ZONE)	KY	07/21/2017	11:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
TRIGG (ZONE)	TRIGG (ZONE)	KY	07/21/2017	11:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
UNION (ZONE)	UNION (ZONE)	KY	07/21/2017	11:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
WEBSTER (ZONE)	WEBSTER (ZONE)	KY	07/21/2017	11:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
MCCRACKEN (ZONE)	MCCRACKEN (ZONE)	KY	07/05/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
WEBSTER (ZONE)	WEBSTER (ZONE)	KY	07/05/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
UNION (ZONE)	UNION (ZONE)	KY	07/05/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
BALLARD (ZONE)	BALLARD (ZONE)	KY	07/05/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
HOPKINS (ZONE)	HOPKINS (ZONE)	KY	07/05/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
LIVINGSTON (ZONE)	LIVINGSTON (ZONE)	KY	07/05/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
LYON (ZONE)	LYON (ZONE)	KY	07/05/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
MARSHALL (ZONE)	MARSHALL (ZONE)	KY	07/05/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
CALDWELL (ZONE)	CALDWELL (ZONE)	KY	07/05/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
CALLOWAY (ZONE)	CALLOWAY (ZONE)	KY	07/05/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
CARLISLE (ZONE)	CARLISLE (ZONE)	KY	07/05/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
CHRISTIAN (ZONE)	CHRISTIAN (ZONE)	KY	07/05/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
MCLEAN (ZONE)	MCLEAN (ZONE)	KY	07/05/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
MUHLENBERG (ZONE)	MUHLENBERG (ZONE)	KY	07/05/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
TODD (ZONE)	TODD (ZONE)	KY	07/05/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
TRIGG (ZONE)	TRIGG (ZONE)	KY	07/05/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
GRAVES (ZONE)	GRAVES (ZONE)	KY	07/05/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
CRITTENDEN (ZONE)	CRITTENDEN (ZONE)	KY	07/05/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
DAVIESS (ZONE)	DAVIESS (ZONE)	KY	07/05/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
FULTON (ZONE)	FULTON (ZONE)	KY	07/05/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K

Location	County/Zone	St.	Date	Time	T.Z.	Type	Mag	Dth	Inj	PrD[3]	CrD[4]
HENDERSON (ZONE)	HENDERSON (ZONE)	KY	07/05/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
HICKMAN (ZONE)	HICKMAN (ZONE)	KY	07/05/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
GRAVES (ZONE)	GRAVES (ZONE)	KY	07/14/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
BALLARD (ZONE)	BALLARD (ZONE)	KY	07/14/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
CARLISLE (ZONE)	CARLISLE (ZONE)	KY	07/14/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
HICKMAN (ZONE)	HICKMAN (ZONE)	KY	07/14/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
FULTON (ZONE)	FULTON (ZONE)	KY	07/14/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
MCCRACKEN (ZONE)	MCCRACKEN (ZONE)	KY	07/14/2018	10:00	CST-6	Excessive Heat		0	0	0.00K	0.00K
Totals:								0	0	0.00K	0.00K

Table X-2. Previous Occurrence, Impacts, Locations of Extreme Cold/Wind Chill, 2013-2018

Location	County/Zone	St.	Date	Time	T.Z.	Type	Mag	Dth	Inj	PrD	CrD
Totals:								2	0	1.500M	0.00K
LAWRENCE (ZONE)	LAWRENCE (ZONE)	KY	01/06/2014	15:00	EST-5	Extreme Cold/Wind Chill		0	0	75.00K	0.00K
GREENUP (ZONE)	GREENUP (ZONE)	KY	01/06/2014	15:00	EST-5	Extreme Cold/Wind Chill		0	0	250.00K	0.00K
BOYD (ZONE)	BOYD (ZONE)	KY	01/06/2014	15:00	EST-5	Extreme Cold/Wind Chill		0	0	100.00K	0.00K
CARTER (ZONE)	CARTER (ZONE)	KY	01/06/2014	15:00	EST-5	Extreme Cold/Wind Chill		0	0	75.00K	0.00K
CARTER (ZONE)	CARTER (ZONE)	KY	01/27/2014	08:00	EST-5	Extreme Cold/Wind Chill		0	0	50.00K	0.00K
GREENUP (ZONE)	GREENUP (ZONE)	KY	01/27/2014	08:00	EST-5	Extreme Cold/Wind Chill		0	0	100.00K	0.00K
LAWRENCE (ZONE)	LAWRENCE (ZONE)	KY	01/27/2014	08:00	EST-5	Extreme Cold/Wind Chill		0	0	50.00K	0.00K
BOYD (ZONE)	BOYD (ZONE)	KY	01/27/2014	08:00	EST-5	Extreme Cold/Wind Chill		0	0	500.00K	0.00K
BOYD (ZONE)	BOYD (ZONE)	KY	02/18/2015	20:00	EST-5	Extreme Cold/Wind Chill		0	0	100.00K	0.00K
CARTER (ZONE)	CARTER (ZONE)	KY	02/18/2015	20:00	EST-5	Extreme Cold/Wind Chill		0	0	50.00K	0.00K
GREENUP (ZONE)	GREENUP (ZONE)	KY	02/18/2015	20:00	EST-5	Extreme Cold/Wind Chill		0	0	100.00K	0.00K
LAWRENCE (ZONE)	LAWRENCE (ZONE)	KY	02/18/2015	20:00	EST-5	Extreme Cold/Wind Chill		0	0	50.00K	0.00K
JOHNSON (ZONE)	JOHNSON (ZONE)	KY	02/19/2015	00:00	EST-5	Extreme Cold/Wind Chill		0	0	0.00K	0.00K
CLAY (ZONE)	CLAY (ZONE)	KY	02/19/2015	00:00	EST-5	Extreme Cold/Wind Chill		0	0	0.00K	0.00K
WAYNE (ZONE)	WAYNE (ZONE)	KY	02/19/2015	00:00	EST-5	Extreme Cold/Wind Chill		1	0	0.00K	0.00K
KNOX (ZONE)	KNOX (ZONE)	KY	02/19/2015	00:00	EST-5	Extreme Cold/Wind Chill		1	0	0.00K	0.00K
LETCHER (ZONE)	LETCHER (ZONE)	KY	02/19/2015	00:00	EST-5	Extreme Cold/Wind Chill		0	0	0.00K	0.00K
KNOX (ZONE)	KNOX (ZONE)	KY	02/19/2015	00:00	EST-5	Extreme Cold/Wind Chill		0	0	0.00K	0.00K
BELL (ZONE)	BELL (ZONE)	KY	02/19/2015	00:00	EST-5	Extreme Cold/Wind Chill		0	0	0.00K	0.00K
WOLFE (ZONE)	WOLFE (ZONE)	KY	02/19/2015	00:00	EST-5	Extreme Cold/Wind Chill		0	0	0.00K	0.00K
KNOTT (ZONE)	KNOTT (ZONE)	KY	02/19/2015	00:00	EST-5	Extreme Cold/Wind Chill		0	0	0.00K	0.00K
MARTIN (ZONE)	MARTIN (ZONE)	KY	02/19/2015	00:00	EST-5	Extreme Cold/Wind Chill		0	0	0.00K	0.00K
HARLAN (ZONE)	HARLAN (ZONE)	KY	02/19/2015	00:00	EST-5	Extreme Cold/Wind Chill		0	0	0.00K	0.00K
PIKE (ZONE)	PIKE (ZONE)	KY	02/19/2015	00:00	EST-5	Extreme Cold/Wind Chill		0	0	0.00K	0.00K
FLOYD (ZONE)	FLOYD (ZONE)	KY	02/19/2015	00:00	EST-5	Extreme Cold/Wind Chill		0	0	0.00K	0.00K
PERRY (ZONE)	PERRY (ZONE)	KY	02/19/2015	00:00	EST-5	Extreme Cold/Wind Chill		0	0	0.00K	0.00K
Totals:								2	0	1.500M	0.00K

Probabilities (Frequencies of Occurrence)

As mentioned above, the list of previous occurrences in Tables X-1 and X-2 list as discrete events counties (or county zones) suffering from potentially the same event. For example, the NCEI Storm Events Database records as four (4) Extreme Cold/Wind Chill events that Boyd, Carter, Greenup, and Lawrence counties suffered from Extreme Cold on February 18, 2015. However, it is apparent that Boyd, Carter, Greenup, and Lawrence counties did not suffer from four (4) events, but rather from one event that affected four counties (or four county "zones").

To establish a probability as a frequency of occurrence, then, a summary of number of events is clarified. Between 2013 and 2018, below are the frequencies of occurrence for Excessive Heat and Extreme Cold/Wind Chill:

Table X-3. Frequencies of Occurrence: Excessive Heat, 2013-2018

Occurrence Number	Date of Previous Occurrence[5]
1	7/27/2015
2	7/21/2017
3	7/5/2018
4	7/14/2018

Table X-4. Frequencies of Occurrence: Extreme Cold/Wind Chill, 2013-2018

Occurrence Number	Date of Previous Occurrence[6]
1	1/6/2014
2	1/27/2014
3	2/18/2015
4	2/19/2015

[5] The interpretation of what constitutes a "previous occurrence" admittedly is being a bit literal here. Looking at the assumed four (4) discrete occurrences of Excessive Heat, it is uncontroversial to assume that there have only actually been three (2) events in the past six (6) years. (2013 is wholly included as year 1.): July of 2015, July of 2017, and July of 2018 saw heat indices exceeding 105 degrees Fahrenheit for more than two (2) hours. Using this definition of "previous occurrence," the rate of occurrence is 0.5 Excessive Heat events per year, or 1 Excessive Heat event every 2 years.

[6] The interpretation of what constitutes a "previous occurrence" admittedly is being a bit literal here. Looking at the assumed four (4) discrete occurrences of Extreme Cold/Wind Chill, it is uncontroversial to assume that there have only actually been two (2) events in the past six (6) years. (2013 is wholly included as year 1.): January of 2014 and February of 2015 saw biting, frostbitten Extreme Cold. Using this definition of "previous occurrence," the rate of occurrence is 0.33 Extreme Cold events per year, or 1 Extreme Cold event every 3.03 years.

Using the above interpretations of discrete events, using the past six (6) years – 2013 is inclusive as year 1 – the following rates of occurrence for Excessive Heat, for Extreme Cold/Wind Chill, and for the two categories combined as Extreme Temperature are:

- *Excessive Heat:*
  - 4 Occurrences over 6 Years = 0.67 Events Per Year, or
  - 1 Event Every 1.49 Years.

- *Extreme Cold/Wind Chill:*
  - 4 Occurrences over 6 Years = 0.67 Events Per Year, or
  - 1 Event Every 1.49 Years.

- *Extreme Temperature:*
  - 8 Occurrences over 6 Years = 1.33 Events Per Year, or
  - 1 Event Every 0.75 Years.

Considering probability as frequency of occurrence and going back to the Disaster Mitigation Act of 2000 that created the hazard mitigation plan requirement, the following adjustments are made to probability as frequency of occurrence.

- *Excessive Heat:*
  - Since 2000, there have been 29 days with Excessive Heat.
  - 29 Occurrences have occurred over 19 years. (2000 is year one.)
    - 29 Occurrences over 19 Years = 1.53 Events Per Year, or
    - 1 Event Every 0.65 Years.

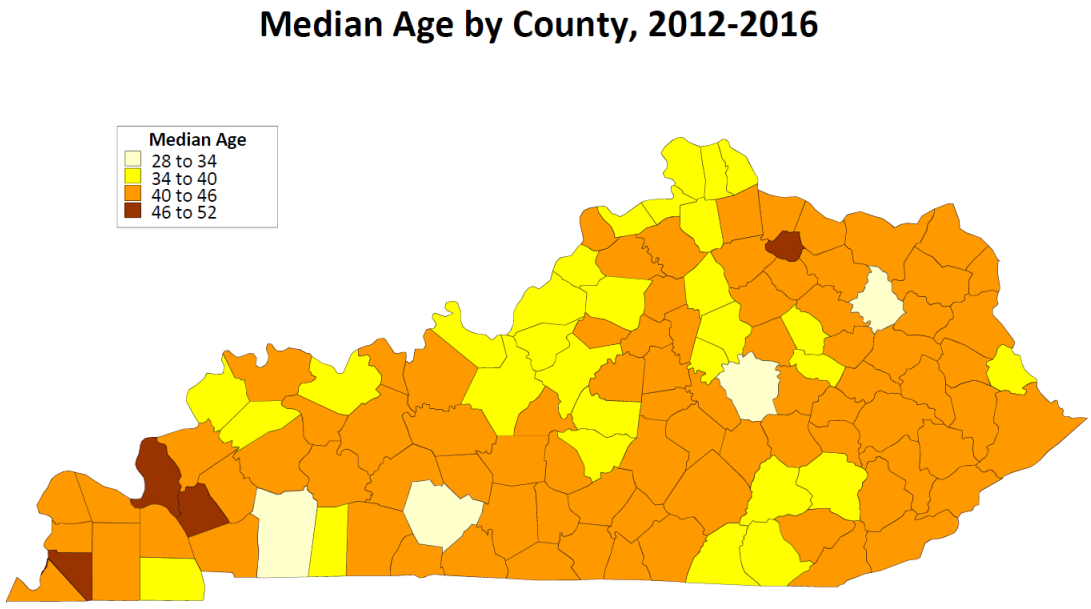
- *Extreme Cold:*
  - Since 2000, there have been 10 days with Extreme Cold/Wind Chill.
  - 10 Occurrences have occurred over 19 years. (2000 is year one.)
    - 10 Occurrences over 19 Years = 0.53 Events Per Year, or
    - 1 Event Every 1.89 Years.

- *Extreme Temperature:*
  - Since 2000, there have been 39 days either with Excessive Heat or Extreme Cold/Wind Chill.
  - 39 Occurrences have occurred over 19 years. (2000 is year one.)
    - 39 Occurrences over 19 Years = 2.05 Events Per Year, or
    - 1 Event Every 0.49 Years.

Vulnerability

It is assumed that the entire Commonwealth of Kentucky is uniformly vulnerable both to Excessive Heat and Extreme Cold/Wind Chill. However, effects from Excessive Heat and Extreme Cold/Wind Chill will vary amidst counties: A primary vulnerability to both Excessive Heat and Extreme Cold/Wind Chill is the elderly population within a state. And Kentucky counties vary in the proportion of its population that is elderly. To convey this particular vulnerability, the Commonwealth of Kentucky Enhanced Hazard Mitigation Plan for 2018 reproduces a graphic from the *Kentucky Annual Economic Report* (KAER) published by Center for Business and Economic Research (CBER) in the Gatton College of Business and Economics at the University of Kentucky (UK)[7].

Figure X-3. Vulnerability to Excessive Heat and Extreme Cold:



Source: U.S. Census Bureau, 2012-2016 5-Year American Community Survey

From the above graphic, the western part of the Commonwealth (within the Pennyrile Area Development District region) has the counties with both the youngest and oldest populations: Christian County has the lowest median age of all of Kentucky's counties (28.3 years old) and Lyon County has the oldest median age of all of Kentucky's counties (49 years old). But, the Commonwealth geography is fairly uniformly distributed with counties having populations where half the population is aged 40 or above.

[7] Childress, Michael T. (ed). 2018. *Kentucky Annual Economic Report 2018*. University of Kentucky, Gatton College of Business and Economics, Center for Business and Economic Research.
Contributors to the Report include: Christopher Bollinger, Adam Childress, Michael Childress, Xiaozhou Ding, Bethany Paris, Veronica Turner, and Jacob Williams.

According to the United States Census Bureau in 2016, 15.6% of Kentucky's population is aged 65 or older. This percentage of elderly population places Kentucky somewhere in the middle of all fifty states in terms of percentage of population that is aged 65 or older.[8] Of similar relevance for the Commonwealth in determining vulnerability to Excessive Heat and Extreme Cold/Wind Chill is percentage of this 15.6% of its population that is considered impoverished. According to the United Health Foundation's Senior Report, Kentucky's percentage of its elderly population (i.e., aged 65 and older) that is impoverished[9] is consistently higher than the nationwide average (but has steadily decreased over the past five years).

Table X-5. Change in Percentage of Elderly Population that is Impoverished, KY and U.S., 2013-2018

	2013	*2014*	*2015*	*2016*	*2017*	*2018*
Percentage of Adults Aged 65+ that is Impoverished: Kentucky	11.9%	11.8%	11.8%	11.3%	11.2%	11.1%
Percentage of Adults Aged 65+ that is Impoverished: U.S.	9.3%	9.3%	9.5%	9.5%	9.0%	9.2%

Kentucky's impoverished elderly will be both more susceptible to Excessive Heat and Extreme Cold/Wind Chill and will have fewer resources and less access to remedies and mitigation from Excessive Heat and Extreme Cold/Wind Chill.

In terms of commonwealth assets, if the entire Commonwealth of Kentucky is uniformly vulnerable to Excessive Heat and Extreme Cold/Wind Chill, then all of Kentucky's owned assets are vulnerable. Thus, below is tabled the total replacement cost value (RCV) of commonwealth assets by county as provided by the Kentucky Finance and Administration Cabinet's Division of State Risk and Insurance Services (DSRI). The potential estimated losses to commonwealth assets from Excessive Heat and (especially) Extreme Cold are equal to total RCVs of all commonwealth assets. This is not a superfluous assumption, especially considering the effects from Extreme Cold. Assets included in DSRI's list include buildings, buildings and contents, and farm buildings values for all assets that the Commonwealth owns and has insured. Critical facilities, universities and their assets, and parks populate the list. Almost every asset in the list has some connection to water supply via piping. Pipes bursting and other deleterious effects from Extreme Cold can create damages that make the total RCV of an asset not seem like an impossible number.

[8] A March 8, 2018 World Atlas list has Kentucky's percentage of its population that is aged 65 and older at 14.8% and ranked 26th of 50 states in percentage of population aged 65 and older. However, the source for the World Atlas statistic is not cited. See: World Atlas. "The U.S. States with the Oldest Populations." https://www.worldatlas.com/articles/the-us-states-with-the-oldest-population.html. [Last Accessed October 23, 2018]. Thus, the 2016 U.S. Census Bureau statistic of 15.6% cited in KAER (2018) is considered here to be a more accurate statistic.

[9] Percentage of adults aged 65 and older who live in households at or below 100% of the poverty threshold

Table X-6. Potential Losses to State Assets from Severe Winter Weather by County

County	Total State Asset RCV
Adair	$ 15,599,957.43
Allen	$ 866,998.36
Anderson	$ 8,612,438.78
Ballard	$ 2,403,332.28
Barren	$ 55,456,232.23
Bath	$ 437,696.66
Bell	$ 44,142,706.30
Boone	$ 57,472,874.73
Bourbon	$ 650,593.61
Boyd	$ 87,491,291.39
Boyle	$ 160,176,891.35
Bracken	$ 407,916.00
Breathitt	$ 44,133,114.44
Breckinridge	$ 20,810,756.45
Bullitt	$ 4,710,725.27
Butler	$ 509,075.46
Caldwell	$ 60,378,899.17
Calloway	$ 707,906,162.16
Campbell	$ 705,367,803.51
Carlisle	$ 709,791.74
Carroll	$ 17,536,494.56
Carter	$ 30,650,145.96
Casey	$ 407,412.80
Christian	$ 173,063,411.69
Clark	$ 7,404,509.93
Clay	$ 17,932,431.51
Clinton	$ 9,598,920.77
Crittenden	$ 1,691,505.81
Cumberland	$ 18,845,292.62
Daviess	$ 85,228,273.76
Edmonson	$ 951,633.50
Elliott	$ 85,873,333.37
Estill	$ 2,017,568.97
Fayette	$ 5,371,398,703.06
Fleming	$ 6,172,714.73
Floyd	$ 61,456,552.89
Franklin	$ 1,601,424,288.46
Fulton	$ 507,505.30
Gallatin	$ 859,830.42
Garrard	$ 1,447,155.00
Grant	$ 3,429,508.95
Graves	$ 15,731,311.26
Grayson	$ 4,636,058.68
Green	$ 363,587.23
Greenup	$ 12,548,548.94
Hancock	$ 332,041.03
Hardin	$ 80,813,474.10
Harlan	$ 53,723,871.42
Harrison	$ 5,961,984.55
Hart	$ 6,396,152.83

County	Total State Asset RCV	
Henderson	$	57,235,511.88
Henry	$	2,491,552.98
Hickman	$	3,124,598.00
Hopkins	$	129,005,433.20
Jackson	$	623,742.76
Jefferson	$	3,167,431,370.73
Jessamine	$	33,034,417.16
Johnson	$	49,429,299.82
Kenton	$	104,207,133.69
Knott	$	16,153,300.82
Knox	$	30,898,391.49
Larue	$	273,502.89
Laurel	$	64,502,923.28
Lawrence	$	3,191,260.76
Lee	$	1,318,783.34
Leslie	$	437,091.11
Letcher	$	7,471,539.50
Lewis	$	817,936.13
Lincoln	$	2,778,591.33
Livingston	$	1,136,851.56
Logan	$	2,775,401.41
Lyon	$	206,810,710.75
Madison	$	1,330,307,365.03
Magoffin	$	662,398.73
Marion	$	373,652.53
Marshall	$	51,257,106.30
Martin	$	1,841,878.86
Mason	$	32,147,839.18
McCracken	$	157,907,123.49
McCreary	$	4,458,805.96
McLean	$	699,739.18
Meade	$	3,790,515.69
Menifee	$	282,609.00
Mercer	$	5,911,709.12
Metcalfe	$	626,271.81
Monroe	$	2,342,417.73
Montgomery	$	820,458.54
Morgan	$	164,310,464.06
Muhlenberg	$	143,077,266.50
Nelson	$	9,422,169.06
Nicholas	$	15,514,943.23
Ohio	$	4,762,669.70
Oldham	$	390,538,925.80
Owen	$	2,351,011.28
Owsley	$	355,966.78
Pendleton	$	3,816,559.27
Perry	$	107,319,960.11
Pike	$	59,250,929.76
Powell	$	16,178,242.94
Pulaski	$	91,544,487.13
Robertson	$	450,777.66
Rockcastle	$	638,454.65

County	Total State Asset RCV
Rowan	$ 647,456,232.22
Russell	$ 41,442,072.77
Scott	$ 19,693,117.93
Shelby	$ 16,425,997.53
Simpson	$ 17,612,477.44
Spencer	$ 3,169,232.07
Taylor	$ 3,024,133.55
Todd	$ 390,799.64
Trigg	$ 32,678,458.60
Trimble	$ 342,689.30
Union	$ 3,160,952.56
Warren	$ 970,045,122.97
Washington	$ 16,420,415.78
Wayne	$ 6,856,669.97
Webster	$ 566,022.75
Whitley	$ 3,358,826.97
Wolfe	$ 618,679.60
Woodford	$ 18,851,990.20

Additionally, the value of the Commonwealth of Kentucky's crops is vulnerable to Excessive Heat and Extreme Cold. Below is the sale value of organic crop totals between and including 2014 and 2016 and the value of total crops produced in Kentucky between and including 2013 and 2016. These values derive from the United States Department of Agriculture (USDA) and its National Agricultural Statistics Service (NASS), i.e., the Census of Agriculture[10]. 2016 is the latest date published for the sale value of organic crops and the production value of total crops and, thus, represents best available data.

Table X-7. Value of Crops for the Commonwealth, 2013-2016

	2013	*2014*	*2015*	*2016*
Crop Totals, Organic, Sales	Not Available	$ 1,876,000	$ 3,393,000	$ 5,388,000
Crop Totals, Production	$3,537,650,000	$2,923,501,000	$2,869,683,000	$2,805,319,000

[10] See: https://quickstats.nass.usda.gov/results/660AC18E-7250-35B8-B7EF-5AC59888D44D [Last accessed October 23, 2018].

Local Jurisdiction Vulnerability and Vulnerability from Local Mitigation Plans

Kentucky's local hazard mitigation plans all generally assume that each of their jurisdictions is equally vulnerable to Excessive Heat and Extreme Cold and assume that all identified local assets are at risk and, thus, estimated potential losses are the estimated losses from all identified assets. These estimated losses are listed below. As with commonwealth-owned and -insured assets, that estimated potential losses are equal to potential loss from losing an entire structure is not too absurd. Freezing pipes, water leakages, and other structural vulnerabilities can require repairs the near the value of a structure.

Unless otherwise stated (in footnotes), the values in the list reflect values for residential, commercial, industrial, agricultural, religious, educational, and governmental building stock.

Table X-8. Summary of Potential Loss Estimates for Severe Winter Storms for Identified Assets from Local Hazard Mitigation Plans

Area Development District	County	Estimated Losses
Barren River ADD	Allen	$ 9,670,842,041.00
	Barren	$ 3,958,251,841.00
	Butler	$ 1,024,039,685.00
	Edmonson	$ 1,167,896,164.00
	Hart	$ 3,747,649,200.00
	Logan	$ 3,980,216,871.00
	Metcalfe	$ 485,802,500.00
	Monroe	$ 1,248,315,078.00
	Simpson	$ 535,815,020.00
	Warren	$ 2,867,998,265.00
Big Sandy ADD	Floyd	$ 1,690,321,000.00
	Pike	$ 2,673,441,700.00
	Johnson	$ 845,535,200.00
	Magoffin	$ 389,568,200.00
	Martin	$ 425,073,100.00

Area Development District	County	Estimated Losses
Bluegrass ADD[11]	Anderson	High
	Bourbon	High
	Boyle	High
	Clark	High
	Estill	High
	Fayette[12]	$ 24,769,019,964.00
	Franklin	High
	Garrard	High
	Harrison	High
	Jessamine	Moderate/High
	Lincoln	High
	Madison	High
	Mercer	High
	Nicholas	Moderate
	Powell	Low
	Scott	Moderate
	Woodford	Moderate
Buffalo Trace ADD	Bracken	$ 1,500,857,120.00
	Fleming	$ 1,870,756,500.00
	Lewis	$ 2,125,877,600.00
	Mason	$ 2,732,050,100.00
	Robertson	$ 650,269,400.00
Cumberland Valley ADD[13]	Bell	$ 172,215,000.00
	Clay	$ 648,626,000.00
	Harlan	$ 551,164,345.00
	Jackson	$ 42,510,000.00
	Knox	$ 263,155,074.00
	Laurel	$ 1,286,433,946.00
	Rockcastle	$ 334,440,764.00
	Whitley	$ 426,394,400.00
FIVCO	Boyd	$ 3,373,238,000.00
	Carter	$ 1,219,671,000.00
	Elliott	$ 272,465,000.00
	Greenup	$ 2,063,959,000.00
	Lawrence	$ 684,745,000.00

[11] Bluegrass ADD uniquely considered estimated potential losses in purely subjective terms. Its regional hazard risk assessment admits the weaknesses apparent in most local hazard mitigation plans that estimating potential losses for most hazard types usually require the unhelpful assumption that all assets are equally vulnerable. Bluegrass ADD defined a Calculated Vulnerability Risk methodology: Past occurrences for each hazard type were recorded regionally and then averaged with local rankings of potential for future events to occur, the overall vulnerability ranking of each hazard, and, relevant to this section, total potential impact. A "LOW" score for potential impact was defined as total cost of impact would be less than $50,000. A "MODERATE" score for potential impact was defined as total cost of impact would be greater than or equal to $50,000 and less than or equal to $500,000. A "HIGH" score for potential impact was defined as total cost of impact would be greater than $500,000.

[12] Fayette County writes its own multi-hazard mitigation plan independently of the Area Development District to which it belongs.

[13] Cumberland Valley ADD estimated potential losses only for critical facilities.

Area Development District	County	Estimated Losses
Gateway ADD	Bath	$ 838,500,000.00
	Menifee	$ 522,656,000.00
	Montgomery	$ 2,469,931,000.00
	Morgan	$ 953,904,000.00
	Rowan	$ 2,215,489,000.00
Green River ADD	Daviess	$ 15,426,498,674.00
	Hancock	$ 4,019,132,528.00
	Henderson	$ 4,711,473,338.00
	McLean	$ 2,090,997,652.00
	Ohio	$ 1,733,482,044.00
	Union	$ 2,990,835,384.00
	Webster	$ 3,861,742,416.00
Kentucky River ADD	Breathitt	$ 61,129,983.00
	Knott	$ 216,264,573.00
	Lee	$ 267,336,625.00
	Leslie	$ 294,032,069.00
	Letcher	$ 362,509,742.00
	Owsley	$ 186,156,853.00
	Perry	$ 452,788,163.00
	Wolfe	$ 187,500,384.00
Kentuckiana Regional Planning and Development Agency (KIPDA)[14]	Bullitt	$ -
	Henry	$ -
	Jefferson[15]	$ 40,733,526,133.00
	Oldham	$ -
	Shelby	$ -
	Spencer	$ -
	Trimble	$ -
Lake Cumberland ADD	Adair	$ 2,448,567,780.00
	Casey	$ 1,697,424,332.00
	Clinton	$ 1,316,116,762.00
	Cumberland	$ 967,288,669.00
	Green	$ 1,348,920,110.00
	McCreary	$ 1,139,879,571.00
	Pulaski	$ 5,049,274,348.00
	Russell	$ 1,613,920,706.00
	Taylor	$ 2,694,903,118.00
	Wayne	$ 1,668,379,353.00

[14] KIPDA estimated potential losses only for government buildings.

[15] Louisville/Jefferson County writes its own multi-hazard mitigation plan independently of the Area Development District to which it belongs. Its loss estimate reflects the value of all of Jefferson County's assets.

Area Development District	County	Estimated Losses
Lincoln Trail ADD	Breckinridge	$ 999,237,848.00
	Grayson	$ 1,328,407,122.00
	Hardin	$ 6,457,655,731.00
	LaRue	$ 804,637,734.00
	Marion	$ 971,747,221.00
	Meade	$ 1,612,379,352.00
	Nelson	$ 2,546,410,178.00
	Washington	$ 622,977,057.00
Northern Kentucky ADD	Boone	$ 15,011,357,000.00
	Campbell	$ 11,032,354,000.00
	Carroll	$1,122,982,000
	Gallatin	$ 662,632,000.00
	Grant	$ 2,231,669,280.00
	Kenton	$ 29,879,599,815.00
	Owen	$ 958,574,982.00
	Pendleton	$ 1,212,853,158.00
Pennyrile ADD	Caldwell	$ 596,494,200.00
	Christian	$ 2,942,126,400.00
	Crittenden	$ 321,089,600.00
	Hopkins	$ 1,872,620,000.00
	Livingston	$ 430,254,000.00
	Lyon	$ 532,324,000.00
	Muhlenberg	$ 1,063,050,000.00
	Todd	$ 440,922,000.00
	Trigg	$ 953,316,000.00
Purchase ADD	Ballard	$ 545,949,576.00
	Calloway	$ 2,355,178,011.00
	Carlisle	$ 234,857,047.00
	Fulton	$ 277,810,192.00
	Graves	$ 1,886,576,304.00
	Hickman	$ 265,028,387.00
	Marshall	$ 2,457,186,169.00
	McCracken	$ 5,111,587,459.00
	Region CF[16]	$ 3,187,950,000.00

[16] The Purchase ADD did not disaggregate by county the estimated potential losses to its Critical Facilities (CF). So, the $3.187 million-dollar number reflects the additional losses for the whole region from vulnerable critical facilities.

As aforementioned, it is assumed that each jurisdiction in Kentucky is equally and uniformly vulnerable to Excessive Heat and Extreme Cold/Wind Chill. Also as aforementioned, this uniformity assumption can be analyzed for jurisdictional variation by targeting a primary recipient of the hazardous effects from Excessive Heat and Extreme Cold, the elderly and the elderly that are impoverished.

That said, during this 2013-2018 commonwealth-wide planning cycle, Kentucky did receive a rather striking anecdote of the effects from Extreme Cold that serves as extent, impacts, and describes a particular local variant of vulnerability:

The eastern and southeastern parts of Kentucky's geography present a challenge to infrastructure that increases for the counties within this region vulnerability to an effect from Extreme Cold: Water system bursts, leakages, and outages. The mountainous terrain of eastern and southeastern Kentucky makes it exceedingly difficult or cost-ineffective to bury water systems and utilities. Water systems and utilities are exposed to Extreme Cold. In Martin County, for example, 90% of its water loss or water vulnerability derives from leakages due to the systems' exposure to the elements and, particularly, to Extreme Cold.

From February 15, 2015 to February 20, 2015, Extreme Cold (as part of a larger winter storm event that included heavy snow) caused so many water main breaks and water distribution interruptions throughout eastern Kentucky that Kentucky Emergency Management (KYEM) had to provide bottled water regionwide. Specifically, KYEM set up a point-of-distribution (POD) in Pike County where the Kentucky National Guard facilitated the distribution of 80 semi-trucks full of bottled water to 19 counties in eastern Kentucky. The 19 counties in eastern Kentucky received 405,893 gallons of water purchased by KYEM at a cost of $397,775 and received an additional 39,044 gallons of water that was donated.

During this 2015 Extreme Cold event, Kentucky's Emergency Operations Center (EOC) was open for nine (9) days.

Further, this event closed down Interstates 24 and 65 for 16 hours: The Commonwealth opened up 14 shelters (Warming Centers) and transported marooned travelers from their cars to these shelters.

Kentucky's Department for Public Health (KDPH) reported 12 deaths resulting from this Extreme Cold event: Three (3) were related to the overall winter storm (heavy snow) that saw Extreme Cold as a part of the winter storm event and nine (9) were indirect deaths.

A Note on Future Conditions

The Commonwealth of Kentucky Enhanced Hazard Mitigation Plan for 2018 (CK-EHMP 2018) has relied on a recent study on climate conditions from modeling specific to Kentucky that was conducted by the United States Army Corps of Engineers (USACE) and the Ohio River Basin Alliance (ORB Alliance). This study is called *Ohio River Basin: Formulating Climate Change Mitigation/Adaptation Strategies through Regional Collaboration with the ORB Alliance*.

From this study, the Commonwealth of Kentucky assumes the following:

- There has been a gradual warming trend throughout the Ohio River Basin since the late 1970s.
- Precipitation has increased during the latter summer and early fall months since the late 1970s.
- Summer highs and winter lows between 2011 and 2040 will remain generally within what has been observed over that historic period. (But, record temperatures, rainfall, or drought cannot be ruled out.)
- The influence of the jet stream across the Ohio River Basin latitudes increases the *variability* of the weather (and further complicates forecasting future climatic conditions).
- Significant changes in river flow discharges and mean annual air temperatures will not be occurring before 2040. The climate will not vary substantially from what has been experienced between 1952 and 2001.

In other words, there has been gradual warming since the late 1970s. This gradual warming will continue without much significant change until 2040. (After 2040, the modeling in the study predicts temperatures may rise one (1) degree every decade through 2099.) Further, part of this gradual warming since the late 1970s involves precipitation increases. Precipitation increases affects nearly every hazard identified in this hazard mitigation plan: Landslides are triggered by precipitation; sinkholes flood with increased precipitation; flash flooding increases from severe storms; and winter storms either increase or become more severe.

The variability interpretation also is interesting and applicable to expected future conditions for Kentucky's identified hazards:

With gradual warming and its effects on summer highs and winter lows, with increased precipitation, and with increased variability of the weather, it is expected that the probability (or, rather, the frequency and/or severity) of Excessive Heat and Extreme Cold events will increase.