3.3.2.4 <u>Severe Winter Storms</u>

I. Background

Definitions:

Winter Storm: According to the National Severe Storms Laboratory (NSSL), a winter storm is an event in which the main types of precipitation are snow, sleet or freezing rain. A winter storm is a combination of heavy snow, blowing snow and/or dangerous wind chills. A winter storm can be a life-threatening event. A **severe winter storm** consists of one or more of the following elements: blinding wind-driven snow, extreme cold, icy roads, avalanches and downed trees and power lines. All winter storms can be dangerous and result in injuries, loss of life and property damage. The effects of a winter storm can impact a region for extended periods of time. Most deaths from winter storms are not a direct result of the storm itself, but rather a result of traffic accidents on icy roads, heart attacks while shoveling snow and hypothermia from prolonged exposure to cold.

Winter storms form just like any other storm at other times of the year. The right combination of ingredients is necessary for a winter storm to develop. The three basic components of a winter storm are cold air, lift and moisture. Below freezing temperatures in the clouds and near the ground are essential to make snow and/or ice. Lift is necessary to raise moist air to form clouds and cause precipitation. Lift occurs when warm air collides with cold air and is forced to rise over the cold dome. The boundary between a warm and cold air mass is called a front. Moisture must be present to form clouds and result in precipitation. Air moving across a lake or large body of water such as an ocean, is an excellent source of moisture.

Blizzard: A blizzard is a dangerous winter storm composed of a combination of blowing snow and wind that results in very low visibility. Heavy snowfalls and severe cold often accompany blizzards but are not required elements. At times, strong wind picks up ground snow and creates a ground blizzard. Blizzards contain winds over 35 mph and reduce visibility to ¼ miles or less for at least three hours.

Ice Storm: An ice storm results in the accumulation of at least .25” of ice on exposed surfaces. Ice storms create hazardous driving and walking conditions. Power outages and property damage can occur when tree branches and power lines snap under the weight of the accumulated ice.

Snow: Snowflakes are collections of ice crystals that cling to each other as they fall to the ground. Wintertime clouds will produce snow as long as the top layer of the storm is cold enough to create snowflakes. Precipitation will continue to fall as snow when the temperature remains at or below 0 degrees Celsius. The following is a summary of snow events:

- Snow Flurries: Light snow falling for a short duration and resulting in no accumulation or a light dusting
- Snow Shower: Snow falling at differing intensities for brief periods of time with some accumulation possible

- Snow Squall: A brief, intense snow shower, accompanied by strong and gusty winds with possible significant accumulation, defines a snow squall. This event usually occurs in the Great Lakes Region.
- Blowing Snow: Wind driven snow that reduces visibility and causes significant drifting. Blowing snow may occur when snow is falling and/or loose ground snow is picked up by the wind.

Sleet: Sleet occurs when snowflakes partially melt when falling through a shallow layer of warm air resulting in slushy drops that refreeze as they fall through a deep layer of freezing air above the surface and reach the ground as frozen rain drops that bounce on impact.

Freezing Rain/Ice Storm: Freezing rain occurs when snowflakes fall through a warmer layer of air and melt completely. When this rain falls through another thin layer of freezing air just above the surface of the ground, it doesn't have time to refreeze before hitting the ground. Because the rain is "supercooled," it instantly freezes upon contact with anything that is at or below 0 degrees C, and creates a glaze of ice on the ground, trees, power lines, or other objects. A significant accumulation of freezing rain lasting several hours, or more is called an ice storm.

2009 Ice Storm, Vine Grove. *Source: LTADD Archive.*

Facts

- Winter storms come in different sizes and are created by different combinations of atmospheric conditions and local geography but can occur anywhere in the United States.
- Winter storms usually occur between the end of October and the end of March in the U.S.
- Winter storms can last for days and be accompanied by high winds, freezing rain or sleet, heavy snowfall, and cold temperatures.
- The aftermath of a winter storm can impact a community or region for a day, weeks, or even months.

Effects

Snow and Ice Accumulation

Snow and ice accumulation on roads and surfaces can result in several adverse effects. Roads and sidewalks become dangerous and, at times, impassable resulting in vehicular accidents, falls, road closures, and delayed response time from emergency agencies. Snow and ice accumulation on trees, poles, power lines and roofs can result in falling debris that causes property damage and human injuries. People attempting to shovel snow can suffer injuries from their efforts as well. 70% of all weather-related injuries are the result of vehicle accidents. Black ice on roadways is another dangerous hazard, as is thawing and refreezing of snow and ice on surfaces.

Power Outages
Snow and ice events can result in area and regional power outages. Power outages can have a significant social and economic impact on an area and may last for an extended period. Fires and dangerous situations arise from the improper use of kerosene lamps and heaters, candles, and space heaters.

2009 Ice Storm, Nelson County. *Source: LTADD Archive.*

2009 Ice Storm, Vine Grove. *Source: LTADD Archive.*

Extreme Cold
Cold air outbreaks can send temperatures plummeting to single digits or lower and it is far more dangerous to be outside for prolonged periods of time. Some of the major threats are:

- Wind Chill: Wind chill is a measure of what the temperature outside *feels* like when wind speed is factored in. As wind speed increases, more heat can be removed from a body by the wind.
- Frostbite: Frostbite results from prolonged exposure to very cold air. Injury is caused by body tissue becoming frozen. Extremities such as fingers and toes are the most susceptible to frostbite.
- Hypothermia: Hypothermia is like frostbite and occurs when the body is exposed to prolonged cold. Hypothermia occurs when the body temperature drops below 95 degrees Fahrenheit.

Flooding
Depending on the amount of accumulation on the ground, flooding can result when ice and snow begin to melt as temperatures begin to rise.

Snow runoff flooding at White Mills (Hardin County) *Source: News-Enterprise, Neal Cardin Photo*.

II. Profile

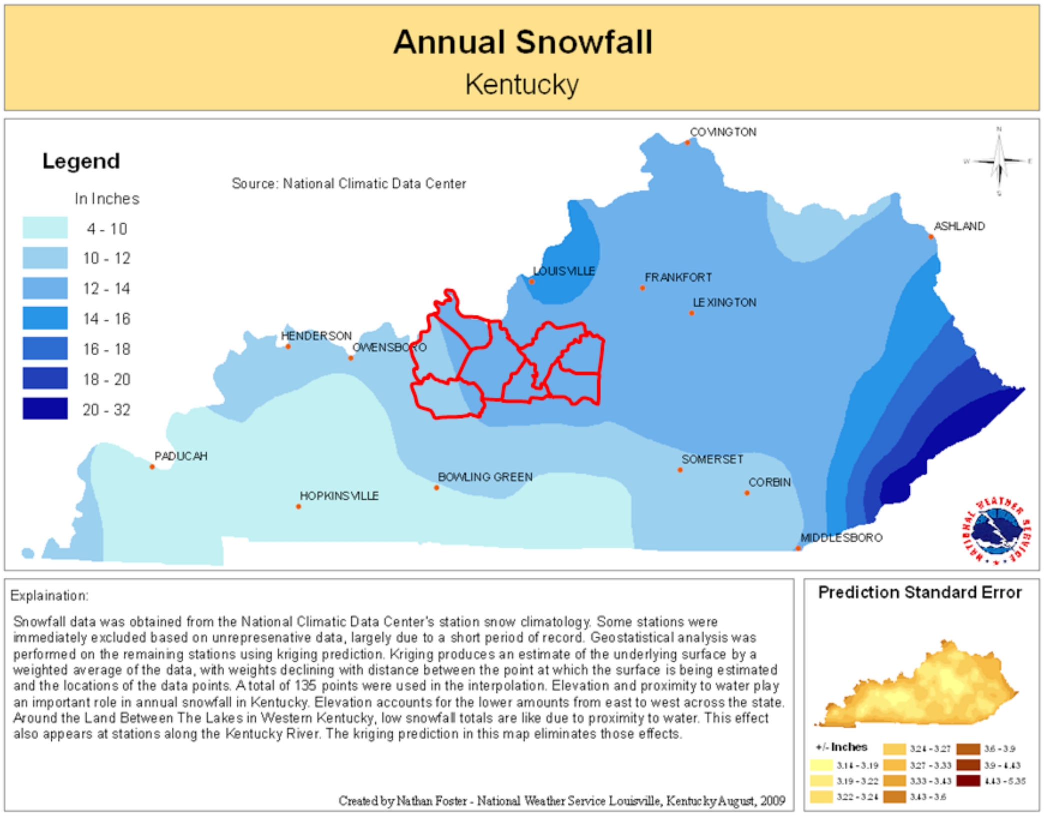
The Kentucky Mesonet data presented below shows minimum temperatures in the Lincoln Trail Region over the last 5 years. Cold temperatures and the severe weather conditions that often accompany them, make the region susceptible to severe winter storms.

Table 3.3.2.4.1

Minimum Temperature (F) Table for Lincoln Trail Region from 2016 to 2021 Source: Kentucky Mesonet							
Location	2016	2017	2018	2019	2020	2021	Average
Breckinridge	3.9	2.4	-1.9	3.3	11.5	1	3.37
Grayson	0.3	1.6	-1.6	2.9	10.7	0.3	2.37
Hardin	1.1	0.4	-2.7	4	9.5	-1.4	1.82
Larue	5.7	3.3	-2.2	5.8	9.5	4.7	4.47
Marion	2.4	-0.8	-5.9	1.9	10.5	4.9	2.17
Meade	0.3	1.4	-6.6	-2.1	8.2	-3.5	-0.39
Nelson	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Washington	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average	2.28	1.38	-3.48	2.63	9.98	1	Five-year Average: 2.3

Note: Nelson County and Washington County lack data due to not having a Mesonet station within their borders.

Kentucky's geographic location makes it vulnerable to extreme winter weather. The State's proximity to the Gulf of Mexico, provides the moisture source for precipitation, while the region is far enough north to be influenced by polar air masses. Low-pressure systems can bring heavy snow to Kentucky that normally track eastward across the southern United States before tracking toward the northeast.



The Lincoln Trail Region is outlined in red above. Breckinridge and Grayson Counties fall predominately in the 10–12-inch range. Hardin, LaRue, Marion, Meade, Nelson, and Washington Counties fall entirely in the 12–14-inch range.

III. Analysis

The analysis for determining the threat of winter storms as a local hazard, involved identifying the conditions that produce winter storms, along with the types of severe winter weather that occur. Data was also tracked concerning the number of events that occur in the Region over time. Sources used to gather information include the National Weather Service, Kentucky Mesonet, the National Climatic Data Center, and Kentucky and County Emergency Management.

The Winter Storm of 2009 began on January 28, 2009, and left the Region devastated. Icy rain turned into solid ice that left the entire eight-county area without power, water, and phone service. Roads were closed and power lines and poles snapped. Many were without power for weeks and the cleanup effort ran well into the late summer months. The State declared a disaster and FEMA issued disaster declaration #1818. Mitigation money from this disaster enabled many local jurisdictions to purchase emergency backup generators, bury power lines, and replace or repair damaged bridges. The chart below illustrates the impact the local Counties reported because of the 2009 Ice Storm.

Table 3.3.2.4.2 – 2009 Winter Storm Impact

County	Days Without Power	Injuries Reported	Deaths Reported	Local Economic Impact*
Breckinridge	Up to 3 weeks	3	0	$1.2-1.5 million
Grayson	Up to 3 weeks	0	0	$2.2 million
Hardin	Up to 2 weeks	0	1	$1.2 million
LaRue	Up to 2 weeks	0	0	$600,000
Marion	Up to 1 week	2	0	$245,000
Meade	Up to 2 weeks	24	0	$1.2 million
Nelson	Up to 3 weeks	0	0	$260,000
Washington	Up to 3 weeks	1	0	$375,000
Totals		30	1	$7,280,000
** Reported by local government; Does not include private utility losses, or individuals' losses of property or wages*				

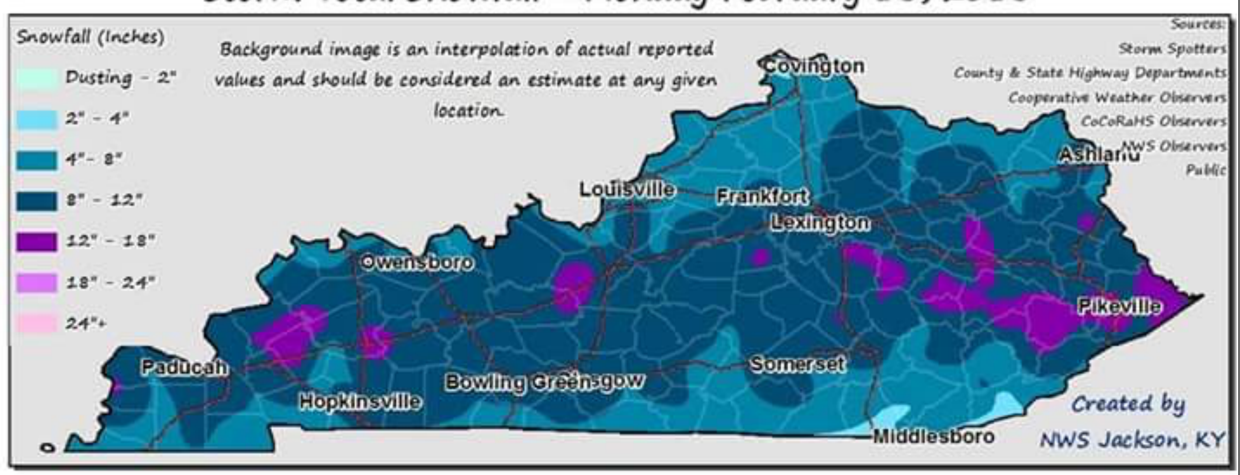
2015 Overturned snowplow in Meade County. *Source: Meade County Emergency Management.*

The winter of 2015 was another devastating one for this region. On February 21, Kentucky Mesonet data shows that between 18 and 19 inches of snow fell in the Hardin County area. Beginning on March 4, 2015, almost 30" of snow fell throughout the region and shut down I65 through Hardin County for over 14 hours. Thousands of cars, trucks and people were stranded on the interstate.

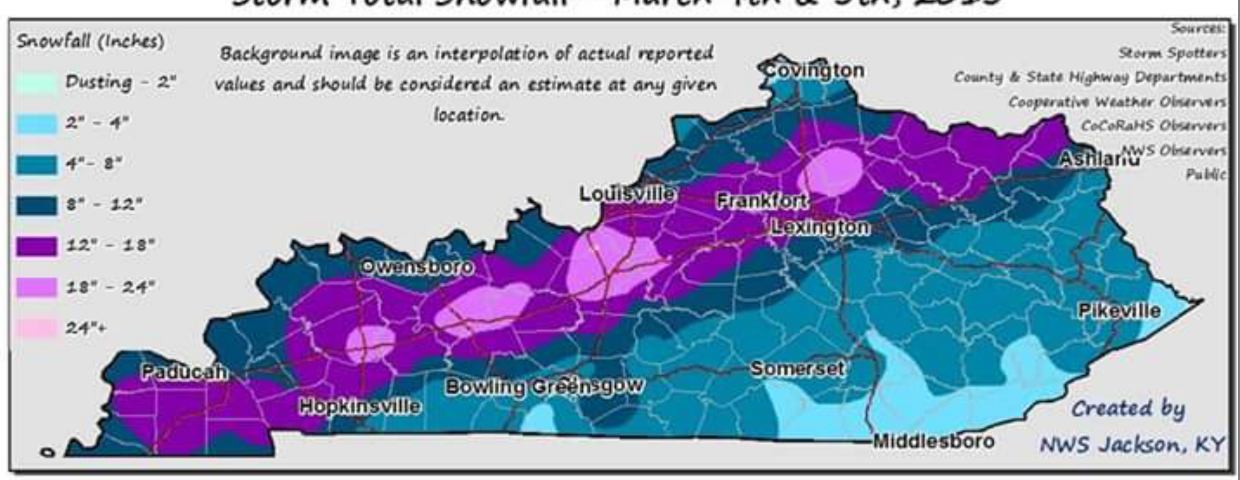
Table 3.3.2.4.3 - 2015 Winter Storm Snow Records

County	February 16, 2015 Snowfall Amount	March 4-5, 2015 Snowfall Amount	Record Place of March 4-5 Snow
Breckinridge	NA	20 inches	1st
Grayson	10 inches	16 inches	
Hardin	13.3 inches	23 inches	1st
LaRue	10 inches	18.3 inches	1st
Marion	11 inches	11 inches	2nd
Meade	8 inches	17 inches	1st
Nelson	13 inches	22 inches	2nd
Washington	12 inches	7.1 inches	
Source: National Weather Service – Louisville, KY			

Storm Total Snowfall - Monday February 16, 2015



Storm Total Snowfall - March 4th & 5th, 2015



The following tables detail the history of winter storms that have been recorded in a given county/jurisdiction within the Lincoln Trail region since 1993. The level of impact is evidenced through the number of lives lost or individual injuries reported, as well as the estimated cost of property and crop damage. This information is reported to the National Climate Data Center (NCDC) and subsequently rolled into the data of the National Centers for Environmental Information (NCEI). For the original plan, data was only available through 2003. The 2010 update provided data thru 30 June 2009. The 2015 update provided data from 1 July 2009 to 30 June2015. This update shows only individual events for the period 1 July 2015 through 14 May 2021. The summary tables show data for the entire periods covered by the various sources. Note that there are many variations in recording the locations of the events over time. In the past this was typically done at a county level. More recently, nearest place names have been used. Because of this, the records in the summation tables regarding the individual incorporated areas should not be considered all encompassing.

When reviewing the tables below, there may appear to be duplication of data across counties. This is due to the nature of a winter storm. One winter storm system most often affects multiple counties and is logged as one event but recorded in each county. Detailed individual county information is not always available; therefore, some data may not reflect the true impact at the county or city level.

Table 3.3.2.4.4 - County Specific Data – Winter Storms, *Source: NCEI*

Breckinridge Co.

LOCATION	DATE	EVENT TYPE	DEATHS DIRECT	INJURIES DIRECT	PROPERTY DAMAGE	CROP DAMAGE
BRECKINRIDGE (ZONE)	1/22/16	Heavy Snow	0	0	0	0
BRECKINRIDGE (ZONE)	2/14/16	Heavy Snow	0	0	0	0
BRECKINRIDGE (ZONE)	1/12/18	Winter Storm	0	0	0	0
BRECKINRIDGE (ZONE)	1/15/18	Winter Storm	0	0	0	0
BRECKINRIDGE (ZONE)	3/11/18	Winter Storm	0	0	0	0
BRECKINRIDGE (ZONE)	3/20/18	Winter Storm	0	0	0	0
BRECKINRIDGE (ZONE)	2/10/21	Ice Storm	0	0	0	0
BRECKINRIDGE (ZONE)	2/14/21	Winter Storm	0	0	0	0

Frozen trees in Breckinridge County in November 2018. *Source: Herald-News*

Grayson Co.

LOCATION	DATE	EVENT TYPE	DEATHS DIRECT	INJURIES DIRECT	PROPERTY DAMAGE	CROP DAMAGE
GRAYSON (ZONE)	1/20/16	Heavy Snow	0	0	0	0
GRAYSON (ZONE)	1/22/16	Heavy Snow	0	0	0	0
GRAYSON (ZONE)	2/14/16	Heavy Snow	0	0	0	0
GRAYSON (ZONE)	1/12/18	Winter Storm	0	0	0	0
GRAYSON (ZONE)	1/15/18	Winter Storm	0	0	0	0
GRAYSON (ZONE)	3/11/18	Winter Storm	0	0	0	0
GRAYSON (ZONE)	11/14/18	Ice Storm	0	0	0	0
GRAYSON (ZONE)	2/10/21	Winter Storm	0	0	0	0
GRAYSON (ZONE)	2/14/21	Winter Storm	0	0	0	0


Frozen scene in Grayson County during a January 2018 winter storm. *Source: K105 News*

Hardin Co.

LOCATION	DATE	EVENT TYPE	DEATHS DIRECT	INJURIES DIRECT	PROPERTY DAMAGE	CROP DAMAGE
HARDIN (ZONE)	1/22/16	Heavy Snow	0	0	0	0
HARDIN (ZONE)	2/14/16	Heavy Snow	0	0	0	0
HARDIN (ZONE)	1/12/18	Winter Storm	0	0	0	0
HARDIN (ZONE)	1/15/18	Winter Storm	0	0	0	0
HARDIN (ZONE)	3/11/18	Winter Storm	0	0	0	0
HARDIN (ZONE)	3/20/18	Winter Storm	0	0	0	0
HARDIN (ZONE)	11/14/18	Ice Storm	0	0	0	0
HARDIN (ZONE)	11/15/18	Ice Storm	0	0	0	0
HARDIN (ZONE)	11/15/18	Ice Storm	0	0	0	0
HARDIN (ZONE)	2/10/21	Ice Storm	1	1	0	0
HARDIN (ZONE)	2/14/21	Winter Storm	0	0	0	0

Downed powerline in Radcliff during a 2018 winter storm. *Source: The News-Enterprise*

LaRue Co.

LOCATION	DATE	EVENT TYPE	DEATHS DIRECT	INJURIES DIRECT	PROPERTY DAMAGE	CROP DAMAGE
LARUE (ZONE)	1/22/16	Heavy Snow	0	0	0	0
LARUE (ZONE)	2/14/16	Heavy Snow	0	0	0	0
LARUE (ZONE)	1/12/18	Winter Storm	0	0	0	0
LARUE (ZONE)	1/12/18	Winter Storm	0	0	0	0
LARUE (ZONE)	1/16/18	Winter Storm	0	0	0	0
LARUE (ZONE)	3/11/18	Winter Storm	0	0	0	0
LARUE (ZONE)	2/10/21	Ice Storm	0	0	0	0
LARUE (ZONE)	2/14/21	Winter Storm	0	0	0	0

Frozen roadway in LaRue County in January 2021. *Source: LaRue County Judge Executive, Blake Durrett*

Marion Co.

LOCATION	DATE	EVENT TYPE	DEATHS DIRECT	INJURIES DIRECT	PROPERTY DAMAGE	CROP DAMAGE
MARION (ZONE)	1/22/16	Heavy Snow	0	0	0	0
MARION (ZONE)	2/14/16	Heavy Snow	0	0	0	0
MARION (ZONE)	1/12/18	Winter Storm	0	0	0	0
MARION (ZONE)	1/16/18	Winter Storm	0	0	0	0
MARION (ZONE)	3/11/18	Winter Storm	0	0	0	0
MARION (ZONE)	2/10/21	Ice Storm	0	0	0	0
MARION (ZONE)	2/14/21	Winter Storm	0	0	0	0

Photo of snow-covered downtown Lebanon after a series of winter activity in February 2021. *Source: The Lebanon Enterprise.*

Meade Co.

LOCATION	DATE	EVENT TYPE	DEATHS DIRECT	INJURIES DIRECT	PROPERTY DAMAGE	CROP DAMAGE
MEADE (ZONE)	1/22/16	Heavy Snow	0	0	0	0
MEADE (ZONE)	2/14/16	Heavy Snow	0	0	0	0
MEADE (ZONE)	1/12/18	Winter Storm	0	0	0	0
MEADE (ZONE)	1/15/18	Winter Storm	0	0	0	0
MEADE (ZONE)	3/11/18	Winter Storm	0	0	0	0
MEADE (ZONE)	3/20/18	Winter Storm	0	0	0	0
MEADE (ZONE)	11/14/18	Ice Storm	0	0	0	0
MEADE (ZONE)	2/10/21	Ice Storm	0	0	0	0
MEADE (ZONE)	2/14/21	Winter Storm	0	0	0	0

School bus covered in ice in Meade County after the February 2021 Ice Storm. *Source: WDRB*

Nelson Co.

LOCATION	DATE	EVENT TYPE	DEATHS DIRECT	INJURIES DIRECT	PROPERTY DAMAGE	CROP DAMAGE
NELSON (ZONE)	1/22/16	Heavy Snow	0	0	0	0
NELSON (ZONE)	2/14/16	Heavy Snow	0	0	0	0
NELSON (ZONE)	1/12/18	Winter Storm	0	0	0	0
NELSON (ZONE)	1/16/18	Winter Storm	0	0	0	0
NELSON (ZONE)	3/11/18	Winter Storm	0	0	0	0
NELSON (ZONE)	3/20/18	Winter Storm	0	0	0	0
NELSON (ZONE)	11/14/18	Ice Storm	0	0	0	0
NELSON (ZONE)	2/10/21	Ice Storm	0	0	0	0
NELSON (ZONE)	2/14/21	Winter Storm	0	0	0	0

Snow- and ice-covered scene in Bardstown, Kentucky during the February 2021 winter weather. *Source: WDRB*

Washington Co.

LOCATION	DATE	EVENT TYPE	DEATHS DIRECT	INJURIES DIRECT	PROPERTY DAMAGE	CROP DAMAGE
WASHINGTON (ZONE)	1/22/16	Heavy Snow	0	0	0	0
WASHINGTON (ZONE)	2/14/16	Heavy Snow	0	0	0	0
WASHINGTON (ZONE)	1/12/18	Winter Storm	0	0	0	0
WASHINGTON (ZONE)	1/16/18	Winter Storm	0	0	0	0
WASHINGTON (ZONE)	3/11/18	Winter Storm	0	0	0	0
WASHINGTON (ZONE)	2/10/21	Ice Storm	0	0	0	0
WASHINGTON (ZONE)	2/14/21	Winter Storm	0	0	0	0

Vehicle accident involving an ice-covered bridge in Washington County in December 2020. *Source: The Springfield Sun.*

Table 3.3.2.4.5 - Summary of Winter Storm Data, Costs

SNOW & ICE	Total Cost	Number Events	Number Years	Total Loss of Life	Total Injuries	Average Cost Per Year	Average Cost Per Event	Average Loss of Life Per Year	Average Loss of Life Per Event	Average Injuries Per Year	Average Injuries Per Event
BRECKINRIDG	$1,411,082	46	61.5	0.31	1.83	$22,944	$30,676	0.01	0.01	0.03	0.04
Cloverport	$0	0									
Hardinsburg	$0	0									
Irvington	$0	0									
GRAYSON	$1,981,398	49	61.5	0.29	3.41	$32,218	$40,437	0.00	0.01	0.06	0.07
Caneyville	$0	0									
Clarkson	$0	0									
Leitchfield	$0	0									
HARDIN	$2,792,155	54	61.5	0.29	3.47	$45,401	$51,707	0.00	0.01	0.06	0.06
Elizabethtown	$0	0									
Radcliff	$0	0									
Sonora	$0	0									
Upton	$0	0									
Vine Grove	$0	0									
West Point	$0	0									
LARUE	$1,050,662	44	61.5	0.29	3.36	$17,084	$23,879	0.00	0.01	0.05	0.08
Hodgenville	$0	0									
MARION	$2,681,555	37	61.5	0.29	3.36	$43,603	$72,474	0.00	0.01	0.05	0.09
Bradfordsville	$0	0									
Lebanon	$0	0									
Loretto	$0	0									
Raywick	$0	0									
MEADE	$1,420,840	47	61.5	0.29	1.81	$23,103	$30,231	0.00	0.01	0.03	0.04
Brandenburg	$0	0									
Ekron	$0	0									
Muldraugh	$0	0									
NELSON	$2,307,155	48	61.5	1.29	3.47	$37,515	$48,066	0.02	0.03	0.06	0.07
Bardstown	$0	0									
Bloomfield	$0	0									
Fairfield	$0	0									
New Haven	$0	0									
WASHINGTON	$2,697,743	47	61.5	0.37	3.48	$43,866	$57,399	0.01	0.01	0.06	0.07
Mackville	$0	0									
Springfield	$0	0									
Willisburg	$0	0									
LTADD	$16,342,589	372	61.5	3.42	24.19	$265,733	$43,932	0.06	0.01	0.39	0.07

NOTE: The historic frequency of a hazard event over a given period of time determines the historic recurrence interval. For example: If there have been 10 Thunderstorm events in the County in the past 5 years, statistically you could expect that there will be 2 events a year.

Realize that from a statistical standpoint, there are several variables to consider. 1) Accurate hazard history data and collection are crucial to an accurate recurrence interval and frequency. 2) Data collection and accuracy has been much better in the past 10-20 years (NCDC weather records). 3) It is important to include all significant recorded hazard events which will include periodic updates to this table.

By updating and reviewing this table over time, it may be possible to see if certain types of hazard events are increasing in the past 10-20 years.

These values should be considered low. More events that have occurred than are documented by the sources used in this table.

All data is compiled at the county level due to extremely limited city specific data, therefore all data and analysis represents incorporated and unincorporated areas inclusively.

Compilation of SHELDUS, NCDC & NCEI. 1967- June 30, 2015.

Table 3.3.2.4.6 - Summary of Winter Storm Data, Events

SNOW & ICE	Number of Events in Historic Record	Number of Years in Historic Record	Number of Events in Past 10 Years	Number of Events in Past 20 Years	Number of Events in Past 50 Years	Historic Recurrence Interval (years)	Historic Frequency % chance/year	Past 10 Year Record Frequency Per Year	Past 20 Year Record Frequency Per Year	Past 50 Year Record Frequency Per Year
BRECKINRIDGE	46	61.5	20	32	41	1.34	74.80%	2	1.6	0.82
Cloverport	0									
Hardinsburg	0									
Irvington	0									
GRAYSON	49	61.5	22	28	45	1.26	79.67%	2.2	1.4	0.9
Caneyville	0									
Clarkson	0									
Leitchfield	0									
HARDIN	54	61.5	26	32	50	1.14	87.80%	2.6	1.6	1
Elizabethtown	0									
Radcliff	0									
Sonora	0									
Upton	0									
Vine Grove	0									
West Point	0									
LARUE	44	61.5	18	23	40	1.40	71.54%	1.8	1.15	0.8
Hodgenville	0									
MARION	37	61.5	12	16	33	1.66	60.16%	1.2	0.8	0.66
Bradfordsville	0									
Lebanon	0									
Loretto	0									
Raywick	0									
MEADE	47	61.5	22	26	43	1.31	76.42%	2.2	1.3	0.86
Brandenburg	0									
Ekron	0									
Muldraugh	0									
NELSON	48	61.5	20	25	44	1.28	78.05%	2	1.25	0.88
Bardstown	0									
Bloomfield	0									
Fairfield	0									
New Haven	0									
WASHINGTON	47	61.5	15	19	39	1.31	76.42%	1.5	0.95	0.78
Mackville	0									
Springfield	0									
Willisburg	0									
LTADD	372	61.5	155	201	335	0.17	604.88%	15.5	10.05	6.7

NOTE: The historic frequency of a hazard event over a given period of time determines the historic recurrence interval. For example: If there have been 10 Thunderstorm events in the County in the past 5 years, statistically you could expect that there will be 2 events a year.

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Compilation of SHELDUS, NCDC & NCEI. 1967- June 30, 2015.

3.3.2.5 Lightning

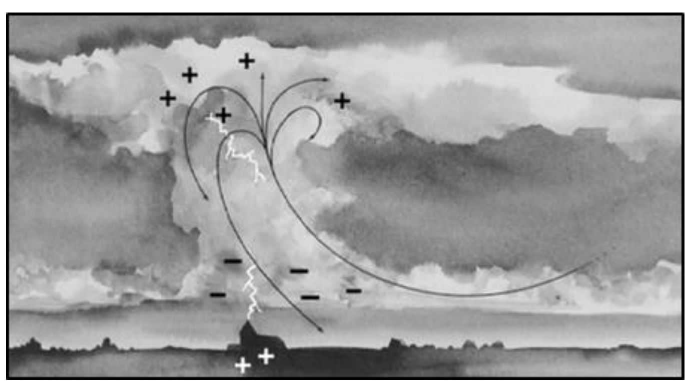
I. Background

Definition: Lightning is a sudden electrostatic discharge during an electrical storm between electrically charged regions of a cloud, between that cloud and another cloud, or between a cloud and the ground. This discharge temporarily equalizes the charged regions in the atmosphere and is called a strike if it hits the ground. Although lightning is always accompanied by thunder, distant lightning may be seen, but be too far away to be heard.

Formation of Lightning

Lightning is usually produced by cumulonimbus clouds, which have bases that are typically 0.6 to 1.25 miles above the ground and tops up to 9.3 miles in height. Lightning originates about 15,000 to 25,000 feet above sea level when raindrops are lifted upward until some of them convert to ice. Cloud to ground lightning begins in this mixed water and ice region. As these particles collide, they create an electric charge and these charges accumulate, filling up the entire cloud. Positive charges or protons form at the top of the cloud while the negative charges or electrons, form at the bottom of the cloud. Because opposites attract, this activity causes a positive charge to build up on the ground beneath the cloud. The electric charge on the ground builds up around anything that sticks up, such as mountains, people, or a single tree. The charge coming up from these points eventually connects with a charge coming down from the clouds and creates a lightning strike. As a charge moves downward from a cloud, it does so in 50-yard increments called step leaders. It keeps moving toward the ground in these steps and produces a channel along which the charge is deposited until it encounters something on the ground that is a good connection. Once a conductive channel form bridges the ionized air between the negative charges in the cloud and the positive charges on ground, a massive electrical discharge follows, and neutralization of the positive surface

Lightning strike in Brandenburg, 2008. *Source: Meade County Emergency Management.*



Source: National Oceanic and Atmospheric Administration; National Lightning Safety Institute charges occurs first. Then an enormous current of positive charges races up the channel toward the thundercloud. This is the "return stroke" and is the most luminous and noticeable part of the lightning discharge.

Types of Lightning

According to the National Oceanic and Atmospheric Administration (NOAA), there are three primary types of lightning. The type of lightning is determined by what is at the "ends" of a flash channel. Intracloud (IC) occurs within a single thundercloud; cloud-to-cloud (CC) starts and ends between two different "functional" thunderclouds; and cloud to ground (CG) lightning primarily starts in a thundercloud and terminates on the Earth's surface. Occasionally, it may reverse direction, and run from the ground to a cloud. There are variations of each type of lightning such as "positive" versus "negative" CG flashes. Each has distinct characteristics that can be measured.

IC lightning is the most frequently occurring type of lightning. This kind of lightning may be observed at great distances at night and is often referred to as "heat lightning."

CC lightning is sometimes referred to as "Anvil Crawler" due to its characteristic of originating from beneath or within the anvil and scrambling through the upper layers of the thunderstorm usually producing multiple branches of dramatic strokes.

CG lightning can occur with both positive and negative polarity. "Negative" lightning is the most common type of CG lightning and originates in the lower negatively charged portion of a thundercloud. Positive lightning originates in the positively charged anvil of the cumulonimbus and may travel several miles from the anvil of the thunderstorm horizontally before veering towards the ground. A positive lightning strike can occur anywhere within several miles of the thunderstorm anvil. Positive lightning makes up less than 5% of all lightning strikes. Positive lightning bolts are considerably hotter and longer than negative lightning. Ground to Cloud lightning is a type of CG lightning that is artificially triggered when tall, positively charged structures on the ground, such as towers on mountains, have been inductively charged by a negative cloud layer above, and is the origin of the lightning strike.

Lightning Dangers

Cloud to ground lightning can damage or destroy property and inanimate objects and can kill or injure people and animals. According to NOAA, lightning strikes the United States about 25 million times a year and has killed an average of 49 people annually. From 2015 to 2019 there have been 121 lightning fatalities in the United States. Almost all lightning occurs in summer but can strike at any time of the year. The following safety precautions are recommended:

- If you see lightning or hear thunder, seek safe shelter immediately, preferably in a building with plumbing and electricity or a metal-topped vehicle with the windows closed.
- Stay off corded phones.
- Avoid Plumbing, electrical equipment and cords, bodies of water or standing water.
- Stay away from windows and doors and stay off porches.
- Do not lie on concrete floors or lean against concrete walls.

- Stay away from trees.
- Stay away from groups of people in the open.
- Rubber soled shoes will not give a person any meaningful protection from lightning.
- A lightning flash is no more than one inch wide.

Vulnerability

Lightning is a hazard that should be taken very seriously. Knowledge about the effects of lightning will help save lives and prevent injuries from lightning. In addition to death and injuries to people and animals alike, lightning causes fires and property damage.

Fatalities and Injuries
In addition to fatalities due to lightning strikes, many injuries occur as well. The chart below illustrates U.S. lightning fatalities between 2010 and May of 2021.

Table 3.3.2.5.1 - U.S. Lightning Fatalities from 2010 to May of 2020			
Year	Male	Female	Total
2010	22	7	29
2011	19	7	26
2012	25	3	28
2013	17	6	23
2014	21	5	26
2015	17	11	28
2016	31	9	40
2017	15	1	16
2018	17	4	21
2019	15	5	20
2020	13	4	17
Source: NOAA and National Weather Service			

Injuries that occur from lightning strikes can range from cardiac arrest to personality changes, and include severe burns, brain damage, memory loss and other long-term effects. It should be noted that deaths and injuries to animals also occurs. The information below compares human fatalities to injury numbers between 1995 and 2013.

Table 3.3.2.5.2

Number of Deaths and Injuries Due to Lightning in the U.S. from 2010 to 2019		
Year	Deaths	Injuries
2010	29	182
2011	26	187
2012	28	139
2013	23	145
2014	26	154
2015	27	130
2016	38	120
2017	16	86
2018	20	82
2019	20	100
TOTAL	253	1325
Source: NOAA		

Fires and Damage

Fires and property damage result from lightning strikes every year. According to the Insurance Information Institute (III), lightning strikes cost homeowners in the United States about $920 million in 2019 alone, up 1.2% from 2018. The Insurance Information Institute estimates the average lightning claim in 2019 at $11,971, up 2.6% from 2018. The U.S. Department of Commerce and NOAA attributed $41.15 million in property damage as the result of lightning in 2019 and $0.01 million in crop damage, for a total of $41.16 million dollars in damages.

In addition to property damage, lightning starts fires. According to the National Fire Protection Association (NFPA), during the period from 2007 to 2011, U.S. local fire departments responded to an estimated average of 22,600 fires per year because of lightning. Fires started by lightning peak during summer months, are more common in the months of June through August, and usually occur later in the afternoon and early evening. In 2014, home and non-home structure fires started by lightning lead to property damage of $473 million dollars.

In the years 2008 – 2012, federal and state wildland firefighting agencies reported an average of 9,000 wildland fires started by lightning, to the National Interagency Fire Center. These fires tended to be larger than fires started by human causes. The average fire caused by lightning burned 402 acres, nine times the average area of 45 acres seen in fires caused by human action. Over the ten-year period from 2003 to 2012, forty-two U.S. firefighters were killed as the result of fighting fires caused by lightning strikes. According to data from the U.S. Forest Service, 44% of wildfires across the western United States was caused by lightning and wildfires stemming from lightning strikes were responsible for 71% of areas burned between 1992 and 2015.

The table below shows homeowners' insurance claims and payouts for lightning losses between 2017 and 2019.

Table 3.3.2.5.3

Homeowners Insurance Claims and Payouts for Lightning Losses from 2017 to 2019					
	2017	2018	2019	Percent Change 2018-2019	Percent Change 2017-2019
Number of Claims	85,020	77,898	76,860	-1.30%	-9.60%
Insured Losses ($ Millions)	$916.60	$908.90	$920.10	1.20%	0.38%
Average Cost Per Claim	$10,781	$11,668	$11,971	2.60%	11.00%
Source: Insurance Information Institute, State Farm®					

Lightning Facts:

- Lightning is a giant discharge of electricity accompanied by a brilliant flash of light and a loud crack of thunder.
- A spark of lightning can reach over 5 miles in length and raise the air temperature by as much as 50,000 degrees Fahrenheit.
- A lightning strike contains a hundred million electrical volts.
- The immense heat and other energy given off during a lightning stroke has been found to convert elements in compounds that are found in organisms and may have played a part in the evolution of living things.
- The odds of being struck by lightning in the U.S. in any given year is 1 in 700,00 while the odds of being struck in your lifetime is 1 in 3,000.
- Positive lightning is especially dangerous because it can strike away from the rain core, either ahead of or behind the thunderstorm and can strike as far as 5 to 10 miles from the storm.
- Victims of a lightning strike do not retain any charge and are not "electrified." It is safe to help them.
- An umbrella can increase your chance of being struck by lightning.

- Lightning often strikes the same place repeatedly if it is a tall, isolated object.
- Most lightning victims are in open areas or near a tree.
- Lightning can heat its path through the air to a temperature that is five times hotter than the surface of the sun.
- All thunderstorms contain lightning.
- Volcanic material thrust high into the atmosphere can trigger lightning.
- Lightning also occurs in extremely intense forest fires, surface nuclear detonations, heavy snowstorms, and in large hurricanes.

III. Analysis

To analyze lightning as a threat to the Lincoln Trail Region, the generalized threat of lightning was identified by reviewing historical data.

The following tables outline the occurrences of lightning that have been recorded in a given county/jurisdiction within the Lincoln Trail region since 1960. The level of impact is evidenced through the number of lives lost or individual injuries recorded, as well as the estimated cost of property and crop damage based on information reported to the National Climate Data Center which was subsequently rolled into the National Centers for Environmental Information (NCEI). For the original plan, data was only available through 2003. The 2010 update provided data through 30 June 2009. The 2015 update provided data from 1 July 2009 to 30 June 2015. This update shows only individual events for the period 1 July 2015 through 14 May 2021. The summary tables show data for the entire period as reported by various sources. Note that there are many variations in recording the locations of the events over time. In the past this was typically done at a county level. More recently, nearest place names have been used. Because of this, the records in the summation tables that pertain to individual incorporated areas, should not be considered all encompassing.

Table 3.3.2.5.4 - County Specific Data – Lightning, *Source: NCEI*

No Lightning events were recorded from 1 July 2015 to 15 May 2021 for Hardin, LaRue, Meade or Washington Counties.

Breckinridge Co.

Location	Date	Deaths Direct	Injuries Direct	Property Damage	Crop Damage
MC Daniels	8/31/18	0	0	200000	0

Grayson Co.

Location	Date	Deaths Direct	Injuries Direct	Property Damage	Crop Damage
Grayson	6/26/16	0	2	0	0

Local Story: Grayson County EMS workers struck by lightning outside ambulance in June of 2016. *Source WLKY*

Marion Co.

Location	Date	Deaths Direct	Injuries Direct	Property Damage	Crop Damage
St Joseph	8/7/18	0	0	250000	0

Extension office in Marion County damaged by a lightning strike. *Source: The Lebanon Enterprise.*

Nelson Co.

Location	Date	Deaths Direct	Injuries Direct	Property Damage	Crop Damage
Bardstown	5/11/16	0	0	25000	0

House fire in Nelson County caused by a June 24th lightning strike. *Source: The Kentucky Standard*

Table 3.3.2.5.5 - Summary of Lightning Data, Costs

LIGHTNING	Total Cost	Number Events	Number Years	Total Loss of Life	Total Injuries	Average Cost Per Year	Average Cost Per Event	Average Loss of Life Per Year	Average Loss of Life Per Event	Average Injuries Per Year	Average Injuries Per Event
BRECKINRIDGE	$489,925	26	60.5	0.04	0.36	$8,098	$18,843	0.00	0.00	0.01	0.01
Cloverport											
Hardinsburg											
Irvington											
GRAYSON	$423,574	32	60.5	0.04	4.36	$7,001	$13,237	0.00	0.00	0.07	0.14
Caneyville											
Clarkson											
Leitchfield	$51,500	2	60.5	0	1	$851	$25,750	0.00	0.00	0.02	0.50
HARDIN	$869,962	34	60.5	1.11	2.36	$14,380	$25,587	0.02	0.03	0.04	0.07
Elizabethtown											
Radcliff	$100,000	1	60.5	0	0	$1,653	$100,000	0.00	0.00	0.00	0.00
Sonora											
Upton											
Vine Grove											
West Point											
LARUE	$61,022	33	60.5	0	0	$1,009	$1,849	0.00	0.00	0.00	0.00
Hodgenville											
MARION	$404,253	36	61.5	0.14	0.39	$6,573	$11,229	0.00	0.00	0.01	0.01
Bradfordsville											
Lebanon											
Loretto											
Raywick											
MEADE	$129,715	28	60.5	0	0	$2,144	$4,633	0.00	0.00	0.00	0.00
Brandenburg											
Ekron											
Muldraugh											
NELSON	$932,717	42	61.5	2.12	2.34	$15,166	$22,208	0.03	0.05	0.04	0.06
Bardstown	$55,000	4	61.5	0	1	$894	$13,750	0.00	0.00	0.02	0.25
Bloomfield											
Fairfield											
New Haven	$525,000	2	61.5	2	1	$8,537	$262,500	0.03	1.00	0.02	0.50
WASHINGTON	$223,179	36	61.5	0.12	0.34	$3,629	$6,199	0.00	0.00	0.01	0.01
Mackville											
Springfield											
Willisburg											
LTADD	$4,265,847	276	60.5	5.57	13.15	$70,510	$15,456	0.09	0.02	0.22	0.05

NOTE: The historic frequency of a hazard event over a given period of time determines the historic recurrence interval. For example: If there have been 10 Thunderstorm events in the County in the past 5 years, statistically you could expect that there will be 2 events a year.

Realize that from a statistical standpoint, there are several variables to consider. 1) Accurate hazard history data and collection are crucial to an accurate recurrence interval and frequency. 2) Data collection and accuracy has been much better in the past 10-20 years (NCDC weather records). 3) It is important to include all significant recorded hazard events which will include periodic updates to this table.

By updating and reviewing this table over time, it may be possible to see if certain types of hazard events are increasing in the past 10-20 years.

These values should be considered low. More events that have occurred than are documented by the sources used in this table.

All data is compiled at the county level due to extremely limited city specific data, therefore all data and analysis represents incorporated and unincorporated areas inclusively.

Compilation of SHELDUS, NCDC & NCEI. 1967- June 30, 2015.

Table 3.3.2.5.6 - Summary of Lightning Data, Events

LIGHTNING	Number of Events in Historic Record	Number of Years in Historic Record	Number of Events in Past 10 Years	Number of Events in Past 20 Years	Number of Events in Past 50 Years	Historic Recurrence Interval (years)	Historic Frequency % chance/year	Past 10 Year Record Frequency Per Year	Past 20 Year Record Frequency Per Year	Past 50 Year Record Frequency Per Year
BRECKINRIDGE	26	60.5	1	1	9	2.33	42.98%	0.1	0.05	0.18
Cloverport										
Hardinsburg										
Irvington										
GRAYSON	32	60.5	2	2	12	1.89	52.89%	0.2	0.1	0.24
Caneyville										
Clarkson										
Leitchfield	2	60.5	1	1	2	30.25	3.31%	0.1	0.05	0.04
HARDIN	34	60.5	2	3	13	1.78	56.20%	0.2	0.15	0.26
Elizabethtown										
Radcliff	1	60.5	0	1	1	60.50	1.65%	0	0.05	0.02
Sonora										
Upton										
Vine Grove										
West Point										
LARUE	33	60.5	0	0	8	1.83	54.55%	0	0	0.16
Hodgenville										
MARION	36	61.5	1	1	8	1.71	58.54%	0.1	0.05	0.16
Bradfordsville										
Lebanon										
Loretto										
Raywick										
MEADE	28	60.5	0	0	11	2.16	46.28%	0	0	0.22
Brandenburg										
Ekron										
Muldraugh										
NELSON	42	61.5	2	6	16	1.46	68.29%	0.2	0.3	0.32
Bardstown	4	61.5	2	4	4	15.38	6.50%	0.2	0.2	0.08
Bloomfield										
Fairfield										
New Haven	2	61.5	0	1	2	30.75	3.25%	0	0.05	0.04
WASHINGTON	36	61.5	0	0	9	1.71	58.54%	0	0	0.18
Mackville										
Springfield										
Willisburg										
LTADD	267	61.5	8	13	86	0.23	434.15%	0.8	0.65	1.72

NOTE: The historic frequency of a hazard event over a given period of time determines the historic recurrence interval. For example: If there have been 10 Thunderstorm events in the County in the past 5 years, statistically you could expect that there will be 2 events a year.

Realize that from a statistical standpoint, there are several variables to consider. 1) Accurate hazard history data and collection are crucial to an accurate recurrence interval and frequency. 2) Data collection and accuracy has been much better in the past 10-20 years (NCDC weather records). 3) It is important to include all significant recorded hazard events which will include periodic updates to this table.

By updating and reviewing this table over time, it may be possible to see if certain types of hazard events are increasing in the past 10-20 years.

These values should be considered low. More events that have occurred than are documented by the sources used in this table.

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Compilation of SHELDUS, NCDC & NCEI. 1967- June 30, 2015.

3.3.2.6 Hail

I. Background

According to Merriam Webster, hailstones are layered and can be irregular and clumped together. Hail is composed of transparent ice or alternating layers of transparent and translucent ice at least 1 millimeter (0.039 inch) thick. This ice is deposited on the hailstone as it travels through the cloud. The ice is suspended aloft by air and strong upward motion until its weight is too much to be supported by the updraft and it falls to the ground. Although varied in size, the diameter of hail in the U.S. averages between 2.5cm (1 inch) and golf ball-sized (1.75 inches).

Hail stones in Meade Co. April 2015. *Source: Meade County Emergency Management. Photo Geraldine Shanahan.*

Hailstones larger than 2 cm (0.80 inch) are considered large enough to cause damage. In the United States, the National Weather Service will issue a severe thunderstorm warning if it predicts hail that is 2.5 cm (1 inch) or greater in diameter.

Any thunderstorm that produces hail that reaches the ground is known as a hailstorm. Hailstones can grow to 15 cm (6 inches) and weight more than 0.5 kilograms (1.1 pounds).

Formation

The National Center for Atmospheric Research states that hail is possible within most thunderstorms because it is produced by cumulonimbi and can occur within 2 nautical miles of the parent storm. Hail formation requires an environment of strong, upward air motion within the parent thunderstorm, high liquid content, great vertical extent, large water droplets, and lowered heights of the freezing level. Although hail and sleet are often confused for one another, and both are forms of solid precipitation, sleet falls generally in cold weather while hail growth is greatly inhibited at cold temperatures.

Facts

- The speed at which hail is falling when it hits the ground is determined by the size of the hailstone, the friction of the air it is falling through, the motion of the wind it is falling through, collisions with raindrops or other hailstones, and melting that occurs as the stones fall through warmer air.
- Speeds can range from 20 mph to 110 mph.
- The heaviest hailstone weighed 2.25 pounds and fell in the Gopalganj District of Bangladesh on April 14, 1986,
- The hailstone with the largest diameter officially measured 8 inches and fell in Vivian, South Dakota on July 23, 2010.
- The hailstone with the largest circumference officially measured 18.75 inches and fell in Aurora, Nebraska on June 22, 2003.
- Hailstones can accumulate, and depths of up to a meter have been reported.

- On July 29, 2010, a foot of hail accumulation was reported in Boulder, Colorado.

Source: National Weather Service and National Severe Storms Laboratory

Hazards/Vulnerability

According to the Federal Aviation Association, hail is one of the most significant thunderstorm hazards to aircraft. Hailstones that exceed .5 inches in diameter can cause serious damage to an aircraft within seconds. Accumulations of hailstones on the ground can be a major hazard to aircraft trying to land.

Accumulations of hailstones on the ground can also cause flooding by blocking drains, and hail carried by floodwaters can turn into a snow-like slush that accumulates at lower elevations. Accumulation of hailstones on streets and highways can cause traffic accidents.

Table 3.3.2.6.1 - Hail Conversion Chart

Diameter of Hailstones (inches)	Description
0.50	Marble
0.70	Dime
0.75	Penny
0.88	Nickel
1.00	Quarter
1.25	Half Dollar
1.50	Walnut
1.75	Golf Ball
2.00	Hen Egg
2.50	Tennis Ball
2.75	Baseball
3.00	Tea Cup
4.00	Grapefruit
4.50	Softball

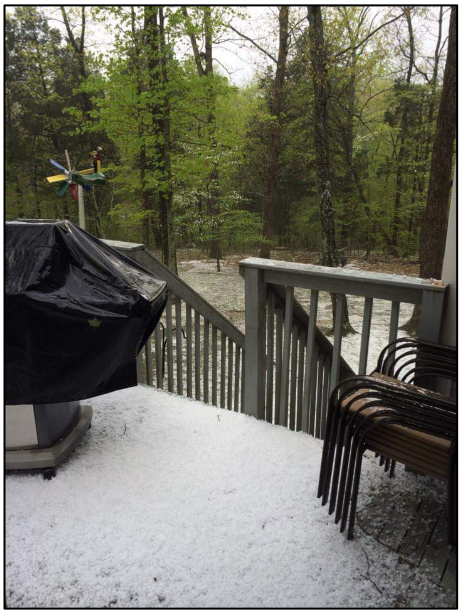
Hail can cause damage to automobiles, aircraft, skylights, glass, livestock, and most commonly, agricultural crops. Wheat, corn, soybeans, and tobacco crops are the most sensitive crops to hail damage. Hailstorms have historically been the cause of costly and deadly events throughout history.

TORRO Hailstorm Intensity Scale (www.torro.org.uk/hscale.php)

	Intensity Category	Typical Diameter (mm)	
H0	Hard Hail	5	No Damage
H1	Potentially Damaging	5 - 15	Slight general damage to plants, crops
H2	Significant	10 - 20	Significant damage to fruit, crops, vegetation
H3	Severe	20 - 30	Severe damage to fruit and crops, damage to glass & plastic structures, paint & wood scored
H4	Severe	25 - 40	Widespread glass damage, vehicle bodywork damage
H5	Destructive	30 - 50	Wholesale destruction of glass, tiled roof damage, significant risk of injury
H6	Destructive	40 - 60	Grounded aircraft bodywork dented, brick walls pitted
H7	Destructive	50 - 75	Severe roof damage, risk of injuries
H8	Destructive	60 - 90	Severe damage to aircraft bodywork (severest recorded in British Isles)
H9	Super Hailstorm	75 - 100	Extensive structural damage. Risk of severe or even fatal injuries to persons caught in the open.
H10	Super Hailstorm	> 100	Extensive structural damage. Risk of severe or even fatal injuries to persons caught in the open.

II. Analysis

To analyze Hail as a threat to the Lincoln Trail Region the generalized threat of hail was identified and historical data on it was researched. The sources of this information are the National Weather Service and the National Climatic Data Center. As the sub-committees reviewed data gathered from these two sources it became very clear that additional sources needed to be consulted. Property and crop damage was not included in the following tables. Insurance estimates from several local providers, indicated a drastically different scenario. For example, in 2002, straight-line winds hurled golf ball and larger size Hail causing an estimated $109M in damages to residential, commercial and city owned properties across the Lincoln Trail Region. Trees were reported down throughout the region. In Marion County, the hardest hit of the eight counties, an estimated two thirds of the county was affected. Thirty windows in the Marion County courthouse were damaged. One local insurance provider reported over 2000 auto and 1000 property claims due to hail.




Hail stones in Meade County, February, and March 2015. *Source: Meade County Emergency Management.*

Other local events of note:

Grayson, Hardin & LaRue Counties

4/26/2011 – National Weather Service reported hail of 2 inches or more. Damage was reported to buildings at Hardin County Fairgrounds. Storms also included confirmed tornados, wind, and flooding.

LaRue County

5/19/2013 - Sheriff's Department Reported: "The ground in some areas in LaRue County was white from the amount of hail that fell Sunday afternoon…the hail reached golf ball size."

Nelson County

4/5/2017 - Hail covered the ground with inches of depth covering most of the western & central part of Nelson County with a sudden downburst to stop every person, machine, or vehicle in motion for twenty minutes during the tantalizing storm.

Summary of Hail in the Lincoln Trail Region

Hailstorms do not adhere to geographic boundaries and have affected each of the eight counties in the Lincoln Trail Region. Many of these storms contained golf ball size or larger hail. The average hailstorm in the Lincoln Trail Region causes damage estimated to be $207,186 per event. The following tables summarize the history of hail events that have been recorded in a given county/jurisdiction within the Lincoln Trail Region since 1950. The impact of these storms is shown by the number of lives lost, individual injuries reported, and estimated economic losses. The level of impact is evidenced through the number of lives lost, individual injuries reported, and the estimated property and crop damage costs. This information was reported to the National Climate Data Center and subsequently rolled into data from the National Centers for Environmental Information (NCEI). Data for the original Regional Plan was only available through 2003. The 2010 update provided data through June 30, 2009. The 2015 update provided data from 1 July 2009 to 30 June 2015. This update shows only individual events for the period 1 July 2015 through 14 May 2021. The summary tables illustrate data for entire periods covered by the different sources. Note that there are many variations in recording the locations of the events over time. In the past, data was not recorded at a county level. More recently, scientists have used nearest place names. Because of this, data in the summation tables pertaining to individual incorporated areas should not be considered all encompassing.

Table 3.3.2.6.2 - County Specific Data – Hail, *Source: NCEI*

BRECKINRIDGE

LOCATION	DATE	MAGNITUDE	DEATHS DIRECT	INJURIES DIRECT	PROP. DAMAGE	CROP DAMAGE
CUSTER	5/1/16	0.75	0	0	0	0
HARDINSBURG ARPT	5/10/16	0.88	0	0	0	0
HARDINSBURG ARPT	5/10/16	1	0	0	0	0
HARDINSBURG ARPT	5/10/16	1	0	0	0	0
HARDINSBURG ARPT	4/5/17	0.88	0	0	0	0
HARNED	4/5/17	1.5	0	0	0	0
DUGAN	4/5/17	0.88	0	0	0	0
HARDINSBURG	4/5/17	0.75	0	0	0	0
MC DANIELS	7/20/18	1	0	0	0	0

GRAYSON

LOCATION	DATE	MAGNITUDE	DEATHS DIRECT	INJURIES DIRECT	PROP. DAMAGE	CROP DAMAGE
SHORT CREEK	12/23/15	0.88	0	0	0	0
SPRING LICK	5/26/16	1.5	0	0	0	0
CLARKSON	7/2/19	1	0	0	0	0

HARDIN

LOCATION	DATE	MAGNITUDE	DEATHS DIRECT	INJURIES DIRECT	PROP. DAMAGE	CROP DAMAGE
VERTREES	5/10/16	0.88	0	0	0	0
PERRYVILLE	5/10/16	1	0	0	0	0
NORTH FOUR CORNERS	5/10/16	0.88	0	0	0	0
LONG VIEW	5/10/16	0.75	0	0	0	0
VERTREES	5/10/16	1	0	0	0	0
ROGERSVILLE	5/10/16	0.75	0	0	0	0
CECILIA	5/10/16	0.88	0	0	0	0
KRAFT	5/11/16	0.75	0	0	0	0
RINEYVILLE	3/27/17	1	0	0	0	0
ROGERSVILLE	3/27/17	0.88	0	0	0	0
LONG VIEW	3/27/17	1	0	0	0	0
HOWE VLY	3/27/17	1	0	0	0	0
GAITHERS	3/30/17	0.88	0	0	0	0
MARTIN BOX	3/30/17	1	0	0	0	0
MARTIN BOX	4/5/17	0.88	0	0	0	0
ELIZABETH TOWN	4/5/17	1	0	0	0	0
VINE GROVE	4/3/18	1	0	0	0	0
VINE GROVE	4/3/18	1.75	0	0	0	0

LARUE

LOCATION	DATE	MAGNITUDE	DEATHS DIRECT	INJURIES DIRECT	PROP. DAMAGE	CROP DAMAGE
HODGENVILLE	12/23/15	0.75	0	0	0	0
ATTILLA	5/10/16	1	0	0	0	0
UPTON	5/10/16	0.75	0	0	0	0
UPTON	5/26/16	0.88	0	0	0	0
HODGENVILLE	7/5/20	1	0	0	0	0
HODGENVILLE	7/5/20	1	0	0	0	0
TONIEVILLE	7/5/20	1	0	0	0	0

MARION

LOCATION	DATE	MAGNITUDE	DEATHS DIRECT	INJURIES DIRECT	PROP. DAMAGE	CROP DAMAGE
RAYWICK	7/13/15	1.25	0	0	0	0
JESSIETOWN	5/10/16	1.25	0	0	0	0
GRAVEL SWITCH	10/20/16	1	0	0	0	0
LORETTO	7/20/18	1.25	0	0	0	0
LEBANON	7/20/18	1	0	0	0	0
PENICKS	7/20/18	1	0	0	0	0

MEADE

LOCATION	DATE	MAGNITUDE	DEATHS DIRECT	INJURIES DIRECT	PROP. DAMAGE	CROP DAMAGE
BATTLETOWN	6/26/15	0.75	0	0	0	0
RHODELIA	12/23/15	1.75	0	0	0	0
BATTLETOWN	12/23/15	0.75	0	0	0	0
EKRON	5/10/16	1.75	0	0	0	0
WOLF CREEK	4/5/17	0.88	0	0	0	0
CONCORDIA	4/8/20	1	0	0	0	0
FAIRFIELD	12/23/15	0.75	0	0	0	0
BOSTON	5/10/16	1	0	0	0	0
COXS CREEK	3/27/17	1.5	0	0	0	0

NELSON

LOCATION	DATE	MAGNITUDE	DEATHS DIRECT	INJURIES DIRECT	PROP. DAMAGE	CROP DAMAGE
FAIRFIELD	3/27/17	0.75	0	0	0	0
COXS CREEK	3/27/17	1	0	0	0	0
BOSTON	4/5/17	1.75	0	0	0	0
BOSTON	4/5/17	1	0	0	0	0
BARDSTOWN	4/5/17	1.75	0	0	0	0
FAIRFIELD	4/5/17	1	0	0	0	0
BLOOMFIELD	4/5/17	0.88	0	0	0	0
FAIRFIELD	4/5/17	1	0	0	0	0
HOWARDSTOWN	4/3/18	1.75	0	0	0	0
LENORE	7/20/18	2.5	0	0	0	0
COXS CREEK	7/20/18	2	0	0	0	0

Damage to a residential structure after an April 2017 Hailstorm in Nelson County. *Source: WLKY*

WASHINGTON

LOCATION	DATE	MAGNITUDE	DEATHS DIRECT	INJURIES DIRECT	PROP. DAMAGE	CROP DAMAGE
MACKVILLE	5/10/16	2	0	0	50000	0
MAUD	4/29/17	1	0	0	0	0
SPRINGFIELD	5/11/17	1.75	0	0	50000	0
ST CATHERINE	7/20/18	1.75	0	0	0	0

Table 3.3.2.6.3 - Summary of Hail Data, Costs

HAIL	Total Cost	Number Events	Number Years	Total Loss of Life	Total Injuries	Average Cost Per Year	Average Cost Per Event	Average Loss of Life Per Year	Average Loss of Life Per Event	Average Injuries Per Year	Average Injuries Per Event
BRECKINRIDGE	$4,925,750	86	58.5	0.01	0.52	$84,201	$57,276	0.00	0.00	0.01	0.01
Cloverport	$0	8	58.5	0	0	$0	$0	0.00	0.00	0.00	0.00
Hardinsburg	$15,000	18	58.5	0	0	$256	$833	0.00	0.00	0.00	0.00
Irvington	$0	7	58.5	0	0	$0	$0	0.00	0.00	0.00	0.00
GRAYSON	$2,438,935	87	57.5	0.01	0.5	$42,416	$28,034	0.00	0.00	0.01	0.01
Caneyville	$0	10	57.5	0	0	$0	$0	0.00	0.00	0.00	0.00
Clarkson	$0	5	57.5	0	0	$0	$0	0.00	0.00	0.00	0.00
Leitchfield	$0	19	56.5	0	0	$0	$0	0.00	0.00	0.00	0.00
HARDIN	$26,768,252	113	58.5	0.01	0.52	$457,577	$236,887	0.00	0.00	0.01	0.00
Elizabethtown	$0	20	58.5	0	0	$0	$0	0.00	0.00	0.00	0.00
Radcliff	$0	4	58.5	0	0	$0	$0	0.00	0.00	0.00	0.00
Sonora	$1,000	7	58.5	0	0	$17	$143	0.00	0.00	0.00	0.00
Upton	$0	1	58.5	0	0	$0	$0	0.00	0.00	0.00	0.00
Vine Grove	$0	3	58.5	0	0	$0	$0	0.00	0.00	0.00	0.00
West Point	$0	2	58.5	0	0	$0	$0	0.00	0.00	0.00	0.00
LARUE	$1,969,355	66	65.5	0.06	0.56	$30,066	$29,839	0.00	0.00	0.01	0.01
Hodgenville	$0	8	65.5	0	0	$0	$0	0.00	0.00	0.00	0.00
MARION	$35,497,179	64	60.5	0.06	2.56	$586,730	$554,643	0.00	0.00	0.04	0.04
Bradfordsville	$0	1	60.5	0	0	$0	$0	0.00	0.00	0.00	0.00
Lebanon	$30,000	7	60.5	0	2	$496	$4,286	0.00	0.00	0.03	0.29
Loretto	$0	3	60.5	0	0	$0	$0	0.00	0.00	0.00	0.00
Raywick	$0	2	60.5	0	0	$0	$0	0.00	0.00	0.00	0.00
MEADE	$25,032,572	74	66.5	0.01	2.52	$376,430	$338,278	0.00	0.00	0.04	0.03
Brandenburg	$35,000	13	66.5	0	0	$526	$2,692	0.00	0.00	0.00	0.00
Ekron	$0	3	66.5	0	0	$0	$0	0.00	0.00	0.00	0.00
Muldraugh	$0	0	66.5	0	0	$0		0.00	0.00	0.00	0.00
NELSON	$22,857,556	85	60.5	0.06	1.56	$377,811	$268,912	0.00	0.00	0.03	0.02
Bardstown	$0	17	60.5	0	0	$0	$0	0.00	0.00	0.00	0.00
Bloomfield	$0	2	60.5	0	0	$0	$0	0.00	0.00	0.00	0.00
Fairfield	$0	4	60.5	0	0	$0		0.00	0.00	0.00	0.00
New Haven	$0	4	60.5	0	0	$0	$0	0.00	0.00	0.00	0.00
WASHINGTON	$11,037,640	55	60.5	0.06	3.56	$182,440	$200,684	0.00	0.00	0.06	0.06
Mackville	$50,000	1	60.5	0	0	$826		0.00	0.00	0.00	0.00
Springfield	$200,000	7	60.5	0	3	$3,306	$28,571	0.00	0.00	0.05	0.43
Willisburg	$0	3	60.5	0	0	$0	$0	0.00	0.00	0.00	0.00
LTADD	$130,527,238	630	66.5	0.28	12.3	$1,962,816	$207,186	0.00	0.00	0.18	0.02

NOTE: The historic frequency of a hazard event over a given period of time determines the historic recurrence interval. For example: If there have been 10 Thunderstorm events in the County in the past 5 years, statistically you could expect that there will be 2 events a year.

Realize that from a statistical standpoint, there are several variables to consider. 1) Accurate hazard history data and collection are crucial to an accurate recurrence interval and frequency. 2) Data collection and accuracy has been much better in the past 10-20 years (NCDC weather records). 3) It is important to include all significant recorded hazard events which will include periodic updates to this table.

By updating and reviewing this table over time, it may be possible to see if certain types of hazard events are increasing in the past 10-20 years.

These values should be considered low. More events that have occurred than are documented by the sources used in this table.

All data is compiled at the county level due to extremely limited city specific data, therefore all data and analysis represents incorporated and unincorporated areas inclusively.

Compilation of SHELDUS, NCDC & NCEI. 1967- June 30, 2015.

Table 3.3.2.6.4 - Summary of Hail Data, Events

HAIL	Number of Events in Historic Record	Number of Years in Historic Record	Number of Events in Past 10 Years	Number of Events in Past 20 Years	Number of Events in Past 50 Years	Historic Recurrence Interval (years)	Historic Frequency % chance/year	Past 10 Year Record Frequency Per Year	Past 20 Year Record Frequency Per Year	Past 50 Year Record Frequency Per Year
BRECKINRIDGE	86	58.5	45	61	73	0.68	147.01%	4.5	3.05	1.46
Cloverport	8	58.5	5	8	8	7.31	13.68%	0.5	0.4	0.16
Hardinsburg	18	58.5	12	17	18	3.25	30.77%	1.2	0.85	0.36
Irvington	7	58.5	4	7	7	8.36	11.97%	0.4	0.35	0.14
GRAYSON	87	57.5	37	57	75	0.66	151.30%	3.7	2.85	1.5
Caneyville	10	57.5	5	9	10	5.75	17.39%	0.5	0.45	0.2
Clarkson	5	57.5	5	5	5	11.50	8.70%	0.5	0.25	0.1
Leitchfield	19	56.5	9	18	19	2.97	33.63%	0.9	0.9	0.38
HARDIN	113	58.5	51	72	96	0.52	193.16%	5.1	3.6	1.92
Elizabethtown	20	58.5	13	20	20	2.93	34.19%	1.3	1	0.4
Radcliff	4	58.5	2	3	4	14.63	6.84%	0.2	0.15	0.08
Sonora	7	58.5	4	7	7	8.36	11.97%	0.4	0.35	0.14
Upton	1	58.5	1	1	1	58.50	1.71%	0.1	0.05	0.02
Vine Grove	3	58.5	3	3	3	19.50	5.13%	0.3	0.15	0.06
West Point	2	58.5	2	1	2	29.25	3.42%	0.2	0.05	0.04
LARUE	66	65.5	27	30	42	0.99	100.76%	2.7	1.5	0.84
Hodgenville	8	65.5	7	8	8	8.19	12.21%	0.7	0.4	0.16
MARION	64	60.5	18	24	37	0.95	105.79%	1.8	1.2	0.74
Bradfordsville	1	60.5	0	1	1	60.50	1.65%	0	0.05	0.02
Lebanon	7	60.5	4	7	7	8.64	11.57%	0.4	0.35	0.14
Loretto	3	60.5	2	3	3	20.17	4.96%	0.2	0.15	0.06
Raywick	2	60.5	2	2	2	30.25	3.31%	0.2	0.1	0.04
MEADE	74	66.5	26	46	56	0.90	111.28%	2.6	2.3	1.12
Brandenburg	13	66.5	8	13	13	5.12	19.55%	0.8	0.65	0.26
Ekron	3	66.5	1	3	3	22.17	4.51%	0.1	0.15	0.06
Muldraugh	0	66.5	0	0	0	0.00	0.00%	0	0	0
NELSON	85	60.5	36	53	61	0.71	140.50%	3.6	2.65	1.22
Bardstown	17	60.5	7	16	17	3.56	28.10%	0.7	0.8	0.34
Bloomfield	2	60.5	1	2	2	30.25	3.31%	0.1	0.1	0.04
Fairfield	4	60.5	4	4	4	15.13	6.61%	0.4	0.2	0.08
New Haven	4	60.5	1	3	4	15.13	6.61%	0.1	0.15	0.08
WASHINGTON	55	60.5	16	22	30	1.10	90.91%	1.6	1.1	0.6
Mackville	1	60.5	1	1	1	60.50	1.65%	0.1	0.05	0.02
Springfield	7	60.5	3	7	7	8.64	11.57%	0.3	0.35	0.14
Willisburg	3	60.5	1	3	3	20.17	4.96%	0.1	0.15	0.06
LTADD	630	65.5	256	365	470	0.10	961.83%	25.6	18.25	9.4

NOTE: The historic frequency of a hazard event over a given period of time determines the historic recurrence interval. For example: If there have been 10 Thunderstorm events in the County in the past 5 years, statistically you could expect that there will be 2 events a year.

Realize that from a statistical standpoint, there are several variables to consider. 1) Accurate hazard history data and collection are crucial to an accurate recurrence interval and frequency. 2) Data collection and accuracy has been much better in the past 10-20 years (NCDC weather records). 3) It is important to include all significant recorded hazard events which will include periodic updates to this table.

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Compilation of SHELDUS, NCDC & NCEI. 1967- June 30, 2015.

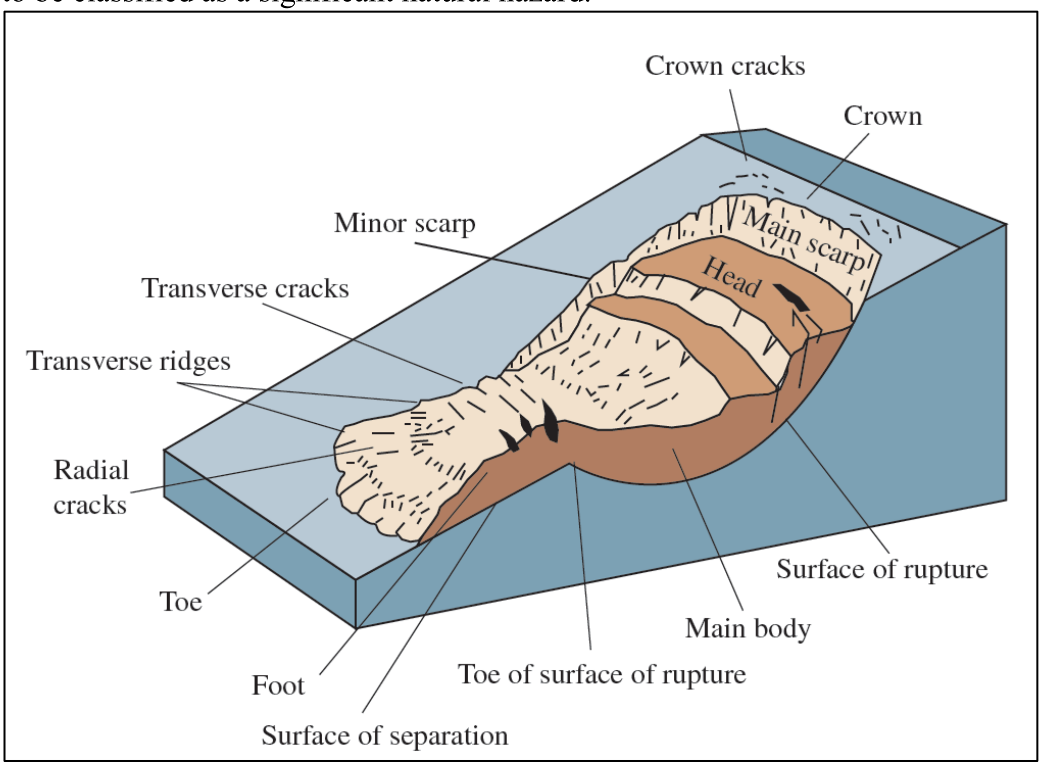
3.3.2.7 <u>Landslides</u>

I. Background

Definition

According to the United States Search and Rescue Task Force, "landslides are rock, earth, or debris flows on slopes due to gravity. They can occur on any terrain given the right conditions of soil, moisture, and the angle of the slope. Integral to the natural process of the earth's surface geology, landslides serve to redistribute soil and sediments in a process that can be in abrupt collapses or in slow gradual slides."

While there are numerous kinds of landslides, they can be triggered by rains, floods, earthquakes, and other natural events, as well as human-made causes such as grading, terrain cutting and filling, excessive development, and vibrations. The factors that cause landslides can be geophysical or man-made and can occur in developed areas, undeveloped areas, or any area where the terrain was altered for roads, houses, utilities, buildings, and even residential lawns. Landslides occur in all fifty states with varying frequency, and more than half of U.S. States have landslide rates sufficient to be classified as a significant natural hazard.



Slump-earth flow showing nomenclature, *Source: USGS Fact Sheet 2004-3072.*

Cause

Landslide is a term frequently used to mean any fairly rapid movement of rocks and sediment downslope. However, a more accurate term to use is "mass wasting." Mass wasting refers to a large variety of mass movement processes that wear away to the Earth's surface.

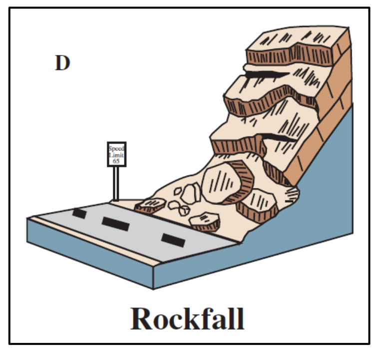
There are three main factors that control the type and rate of mass wasting that occurs at the Earth's surface:

- Slope gradient: The steeper the slope of the land, the more likely that mass wasting will occur.
- Slope consolidation: Sediments and fractured or poorly cemented rocks and sediments are weak, and more prone to wasting.
- Water: When slope materials become saturated with water, they may lose cohesion and begin to flow easily.

The three basic types of mass wasting are:

- Falls – rocks fall or bounce through the air
- Slides – rocks and/or sediment slide along the Earth's surface
- Flows – sediment flows across the Earth's surface

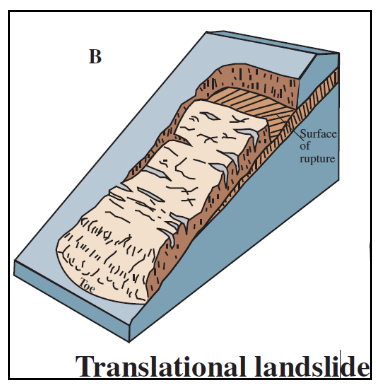
Falls occur as a result of weathering. Steep mountain or hillside slopes are constantly wasting away and are characterized by rocks falling and bouncing down slopes. These falls are triggered by freezing and thawing water, the growth of plants and their roots, earthquakes, or by people hiking on a slope. Falls occur in a matter of seconds, so they are difficult to observe.



USGS Fact Sheet 2004-3072.

Slides occur when a mass of slope material moves as an entire block. The most common form of a slide is a **slump**. A slump happens when a portion of the hillside moves downslope as a result of gravity.

A landslide is called a **flow** if the material moving downslope is being transported as a very thick fluid, rather than as a unified block of material.



USGS Fact Sheet 2004-3072.

Areas prone to landslides include:

- Existing landslides, old or recent
- On or at the base or top of slopes
- In or at the base of minor drainage hollows
- At the base or top of an old fill slope
- At the base or top of a steep cut slope

Areas that are generally safe from Landslides include:

- On hard, non-joined bedrock that has not moved in the past
- On relatively flat-lying areas away from slopes and steep riverbanks
- At the top or along the nose of ridges, set back from the tops of slopes

Features that may be present prior to a major landslide include:

- Springs, seeps, or saturated ground in areas that have not typically been wet before

- New cracks or unusual bulges in the ground, street pavements or sidewalks
- Soil moving away from foundations
- Ancillary structures such as decks and patios tilting and/or moving relative to the main structure
- Tilting or cracking of concrete floors and foundations
- Broken water lines and other underground utilities
- Leaning telephone poles, trees, retaining walls or fences
- Offset fence lines
- Sunken or down dropped roadbeds
- Sudden decrease in creek water levels though rain is still falling or has just recently stopped.
- Sticking doors and windows, and visible open spaces; indication jambs and frames are out of plumb.

Landslide area in Nelson County along the Chaplin River. *Source: LTADD Archive.*

A landslide occurs when the stability of a slope changes from a stable condition to an unstable one. A change in slope stability can occur from several factors that act alone or in concert with one another. Natural causes of landslides include:

- Groundwater (pore water) pressure acting to destabilize a slope
- Loss or absence of vertical vegetative structure, soil nutrients and soil structure; all of these factors can be the result of a wildfire
- Erosion of the toe of a slope by rivers or ocean waves
- Intense rainfall
- Weakening of a slope due to saturation by melting snow and glaciers or by heavy rains
- Earthquakes that add loads to barely stable slopes or earthquake-caused liquefaction that destabilizes slopes
- Volcanic eruptions

Human activities that can affect the occurrence of a landslide include:

- Deforestation, cultivation, and construction that contributes to the destabilization of a fragile slope
- Vibrations from machinery or traffic
- Blasting
- Earthwork that alters the shape of a slope or contributes new loads on an existing slope
- Removal of deep-rooted vegetation that binds colluvium to bedrock in shallow soils
- Construction, agricultural or forestry activities that changes the amount of water which infiltrates the soil

Hazards/Vulnerability

According to the United States Geological Survey causes billions of dollars in damages to public and private property annually and kill multiple people in the United States annually. Landslides occur in all fifty of the states in the U.S. The casualties in the United States are caused primarily by rockfalls, rockslides, and debris flows. Natural disasters are a prime example of humans living in conflict with the environment. Because landslides can cause catastrophic damage and loss of life, it is imperative to have a good understanding of what causes disasters to prevent them from occurring or to avoid development in areas prone to disasters. Sustainable land management and development is an essential tool in reducing the negative impacts that can happen because of landslides.

Rockslide on the Blue Grass Parkway in Hardin County. *Source: Kentucky Geological Survey*

II. Analysis

It is helpful to understand the physiographic characteristics of the Lincoln Trail Region to analyze the risk of landslides in the area. The Kentucky Physiographic Regions map included, shows that our region lies in four Kentucky physiographic regions; the Knobs, the Western Coal Field, the Outer Bluegrass and the Mississippian Plateau or Western Pennyroyal. Each has distinct characteristics that define it and help determine the propensity for landslides. Information for this analysis comes from ARCGIS, Kentucky Geological Survey and historical information from County Emergency Management Agencies.

According to the Kentucky Geological Survey, Kentucky has a combination of steep slopes, excessive water amounts, geology, and slope modifications that are the main causes of landslides. There are over 2,300 landslides in the Kentucky Geological Survey Database. According to the Kentucky Geological Survey, landslides and rock fall cost the state over $4 million annually with a majority of this incurred by the Kentucky Transportation cabinet While damage totals specific to the Lincoln Trail Region are not documented, it is definite that some of Transportation Cabinets repairs were done on local roads. From 2003 to 2013, the Kentucky Hazard Mitigation Grant program funded or will fund projects to acquire landslide-damaged homes or to stabilize an area, totaling $5.3 million. In general, the State and local agencies that respond to or document landslides vary, and data pertaining to the collection, assessment, and documentation of occurrences is not consistent.

To date, Hazard Mitigation funds were used in Nelson County to buy out a home in danger of sliding down a slope. The property was purchased in 2006 and the structure demolished. The land was rezoned to green space in perpetuity. Meade County has imminent need to stabilize a bank slope on the Ohio River that threatens the local water supply, and Breckinridge County has project plans to stabilize slopes that threaten local roads.

Extent
While there are few documented reports of extensive damage because of landslide activity, the eight-county region has natural topographic and geologic features that render it susceptible to landslides when natural events such as ground water, intense rainfall, melting snow and seismic activity are factored in. This is substantiated by the 2006 *Landslide* review written by Yoshimatsu and Abe. Yoshimatsu and Abe identify the Analytical Hierarchic Process (AHP) as a method to determine areas susceptible to landslides. Aerial photographs of areas prone to landslides are "layered." Scores are assigned to each "layer" of the micro-topography and susceptibility to landslides is a function of the summation of scores assigned to each factor of the photographed micro-topography in the landslide prone area. Based on this technology, and the topographic features of the Lincoln Trail Area including karst topography, steep slopes, alluvial soils, and underground water movement, coupled with the regional propensity for heavy rains and melting snow; it can be determined that the region has the potential for landslide hazards.

Table 3.3.2.7.1 - AHP Score of Ranking of Susceptibility of Landslides

Susceptibility Level	AHP Score	Percentage to Total Number of Landslides (%)
Level 1 (High)	62 > AHP Score	5%
Level 2 (Slightly High)	38 < AHP Score	25%
Level 3 (Slightly Stable)	24 < AHP Score	30%
Level 4 (Stable)	AHP Score < 24	40%

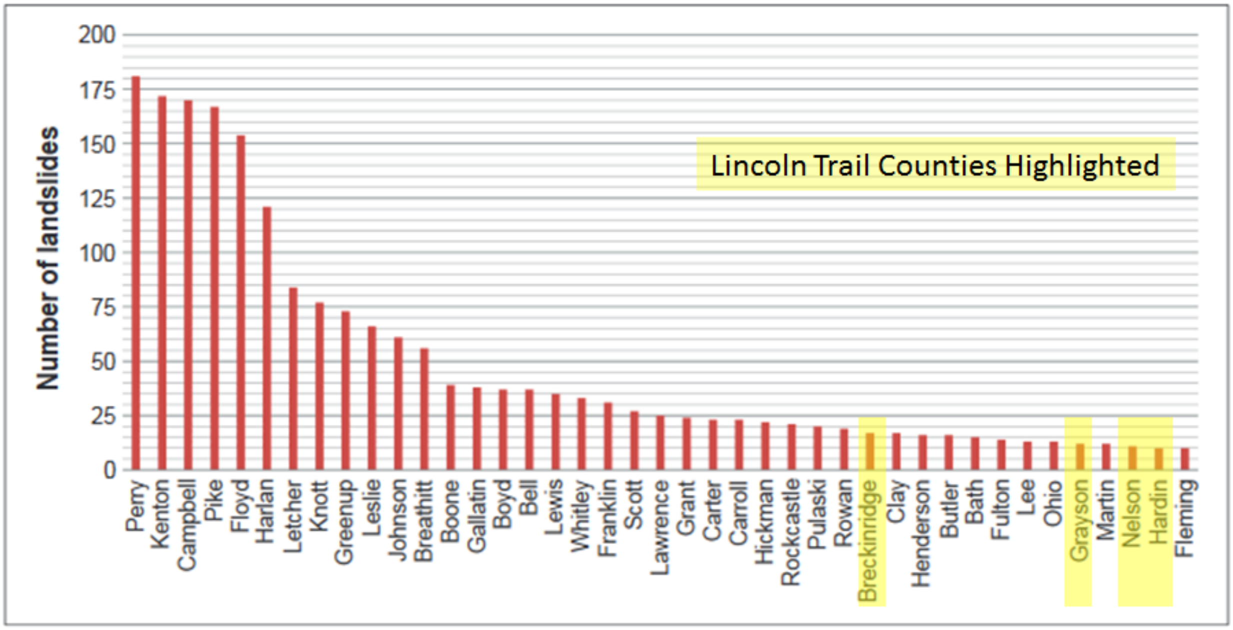
Source: Yoshimatsu, H.; & Abe, S. (2006). "A Review of Landslide Hazards in Japan and Assessment of Their Susceptibility Using an Analytical Hierarchic Process (HP) Method." *Landslides*, 3, 149-158

As previously cited, landslides in this region have the potential to destroy structures, interrupt transportation lines and decimate regional water sources.

Probability

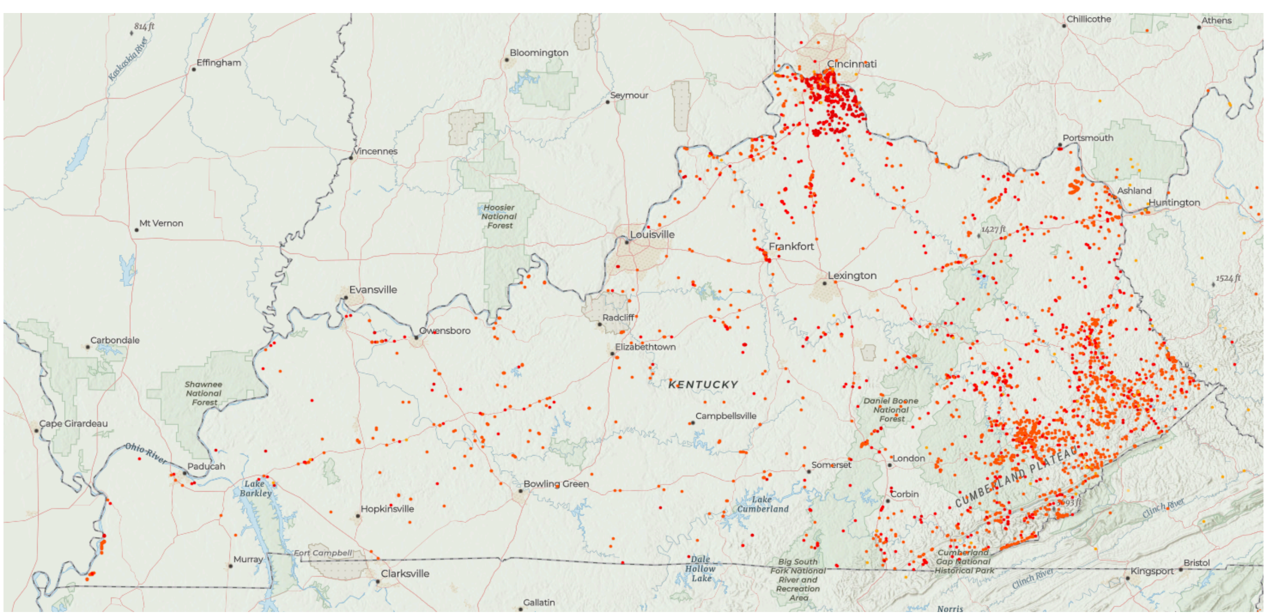
In 2011, Kentucky Geological Survey (KGS) began constructing a landslide inventory database. As of August 20, 2014, the Kentucky Landslide Inventory illustrated by chart 3.3.2.7.1 was completed. The inventory shows the number of documented landslides in the database per county for those counties with 10 or more landslides. In the Lincoln Trail Region there are 49 documented landslides: 16 in Breckinridge County, 12 in Grayson County, 11 in Nelson County and 10 in Hardin County. This yields approximately 3.5 years of data. A raw value for probability for an event occurrence for the Lincoln Trail Region would be historic recurrence interval of 0.07 and a historic frequency, chance per year of 1400%.

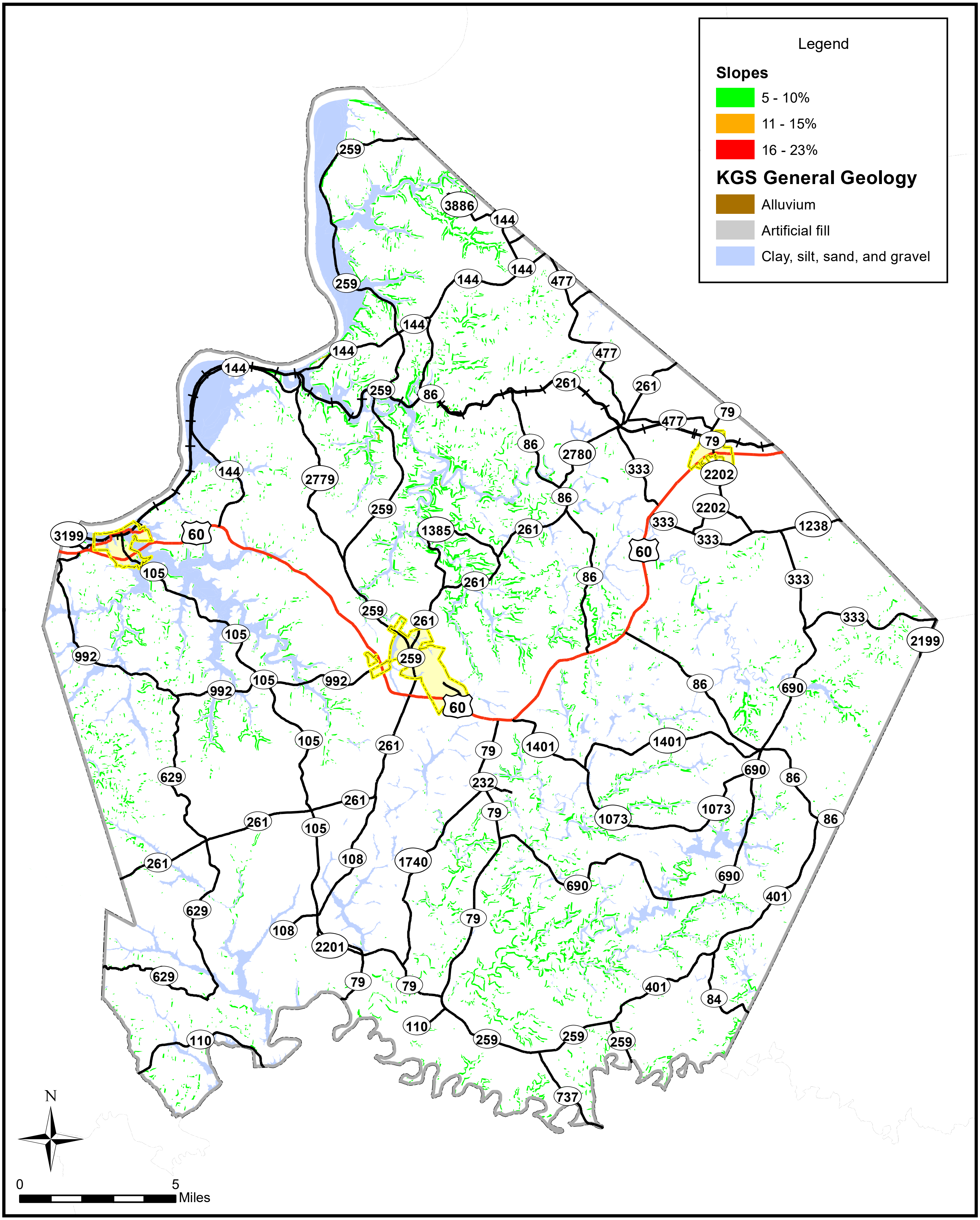
Chart 3.3.2.7.1 - KGS Landslide Inventory, Distribution of Landslides

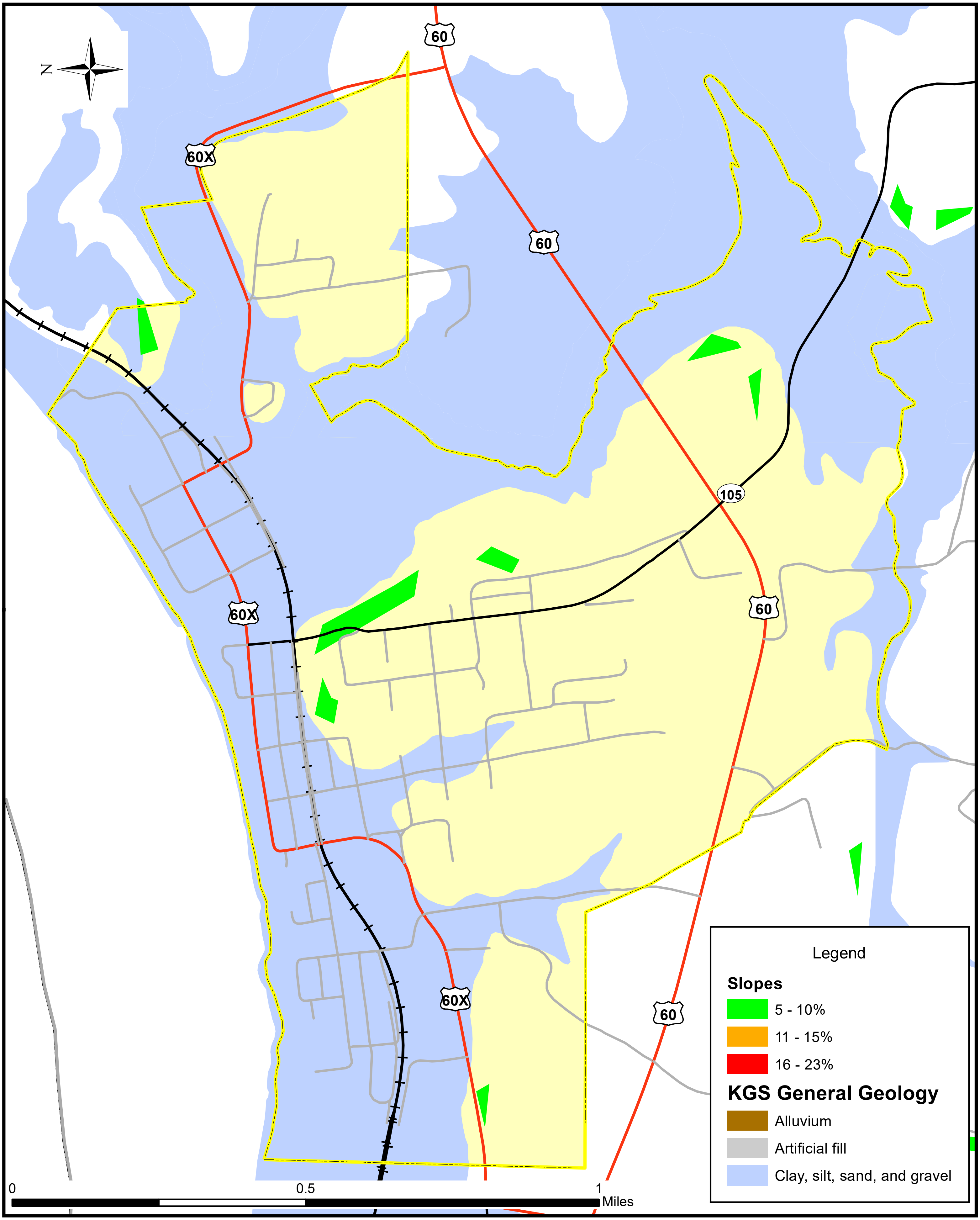


Modified from "Distribution of landslides by county (10 or more landslides)", *Source: KGS "Landslide Inventory: From Design to Application, 2014.*

Note that according to KGS, there is currently no best practice or standard methodology to develop a database that could effectively model landslide susceptibility or risk. Much depends on the ability to collect locations and occurrences. In 2021, a new inventory of landslides such as that shown in the table above has not been created. Below is a map with data from the USGS on recent landslides estimates in Kentucky. Each dot is an estimated landslide. Eastern Kentucky has more landslides according to the map, but the Lincoln Trail region does have some landslides.




Legend
Slopes
5 - 10%
11 - 15%
16 - 23%
KGS General Geology
Alluvium
Artificial fill
Clay, silt, sand, and gravel
N
0
5
Miles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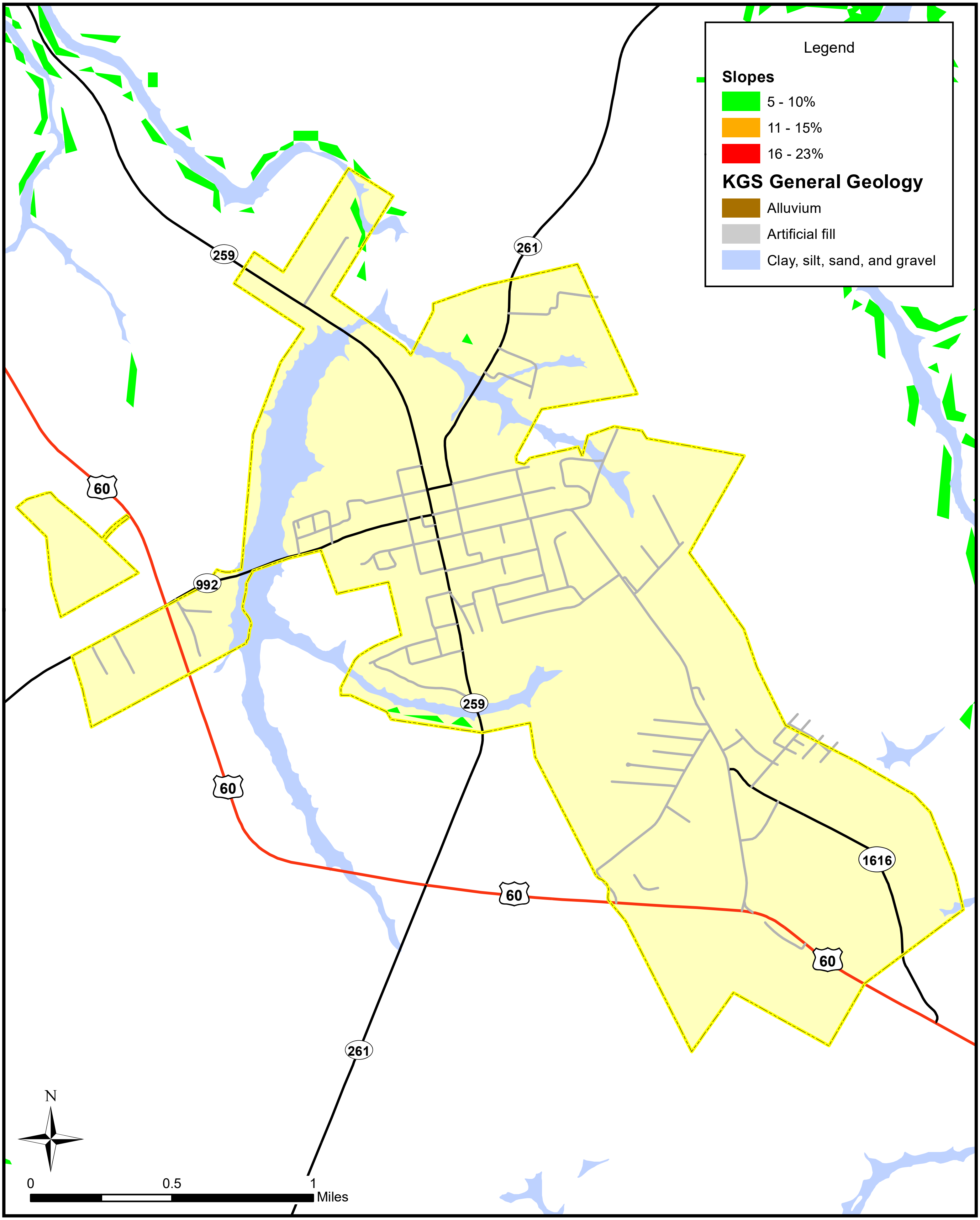
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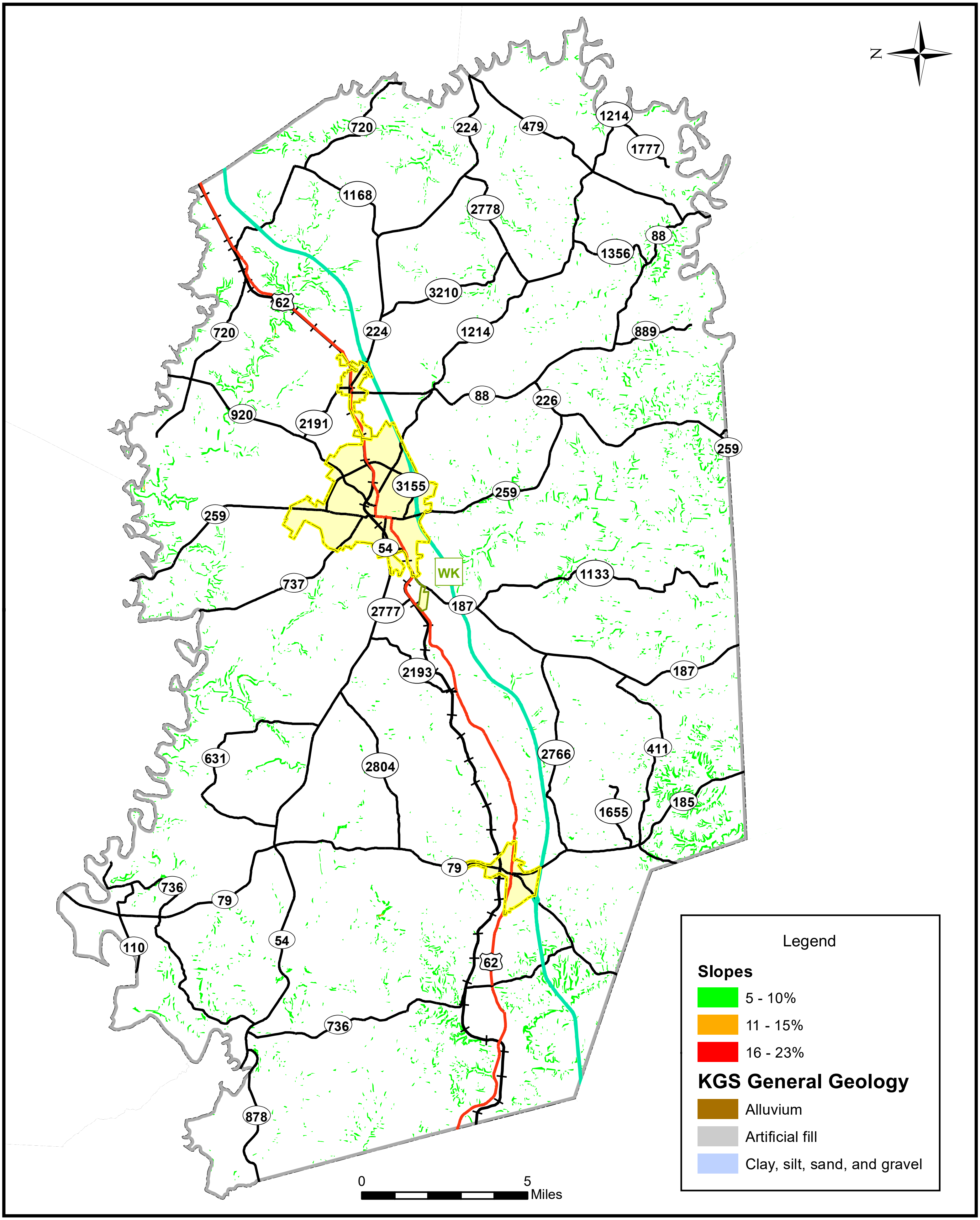
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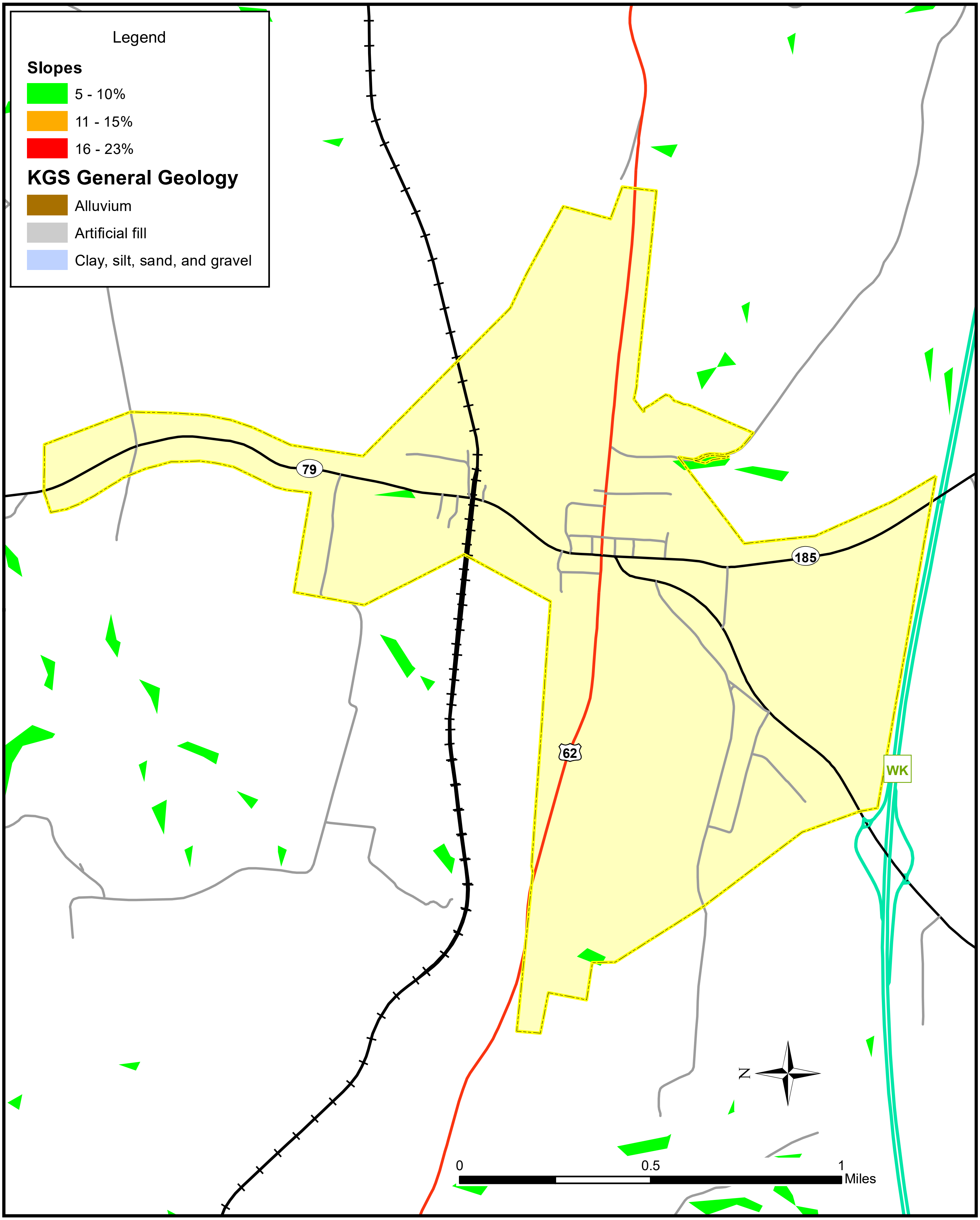
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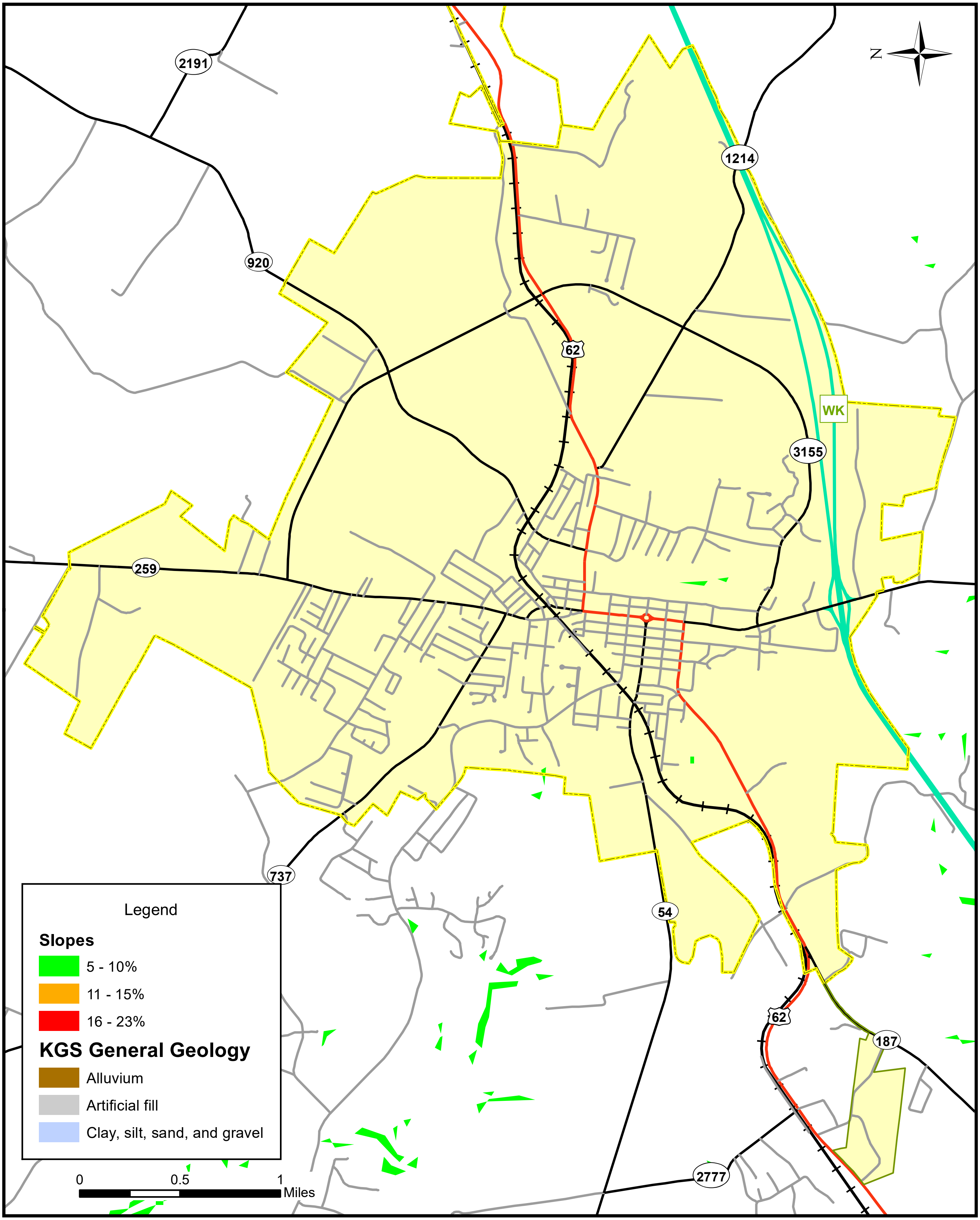
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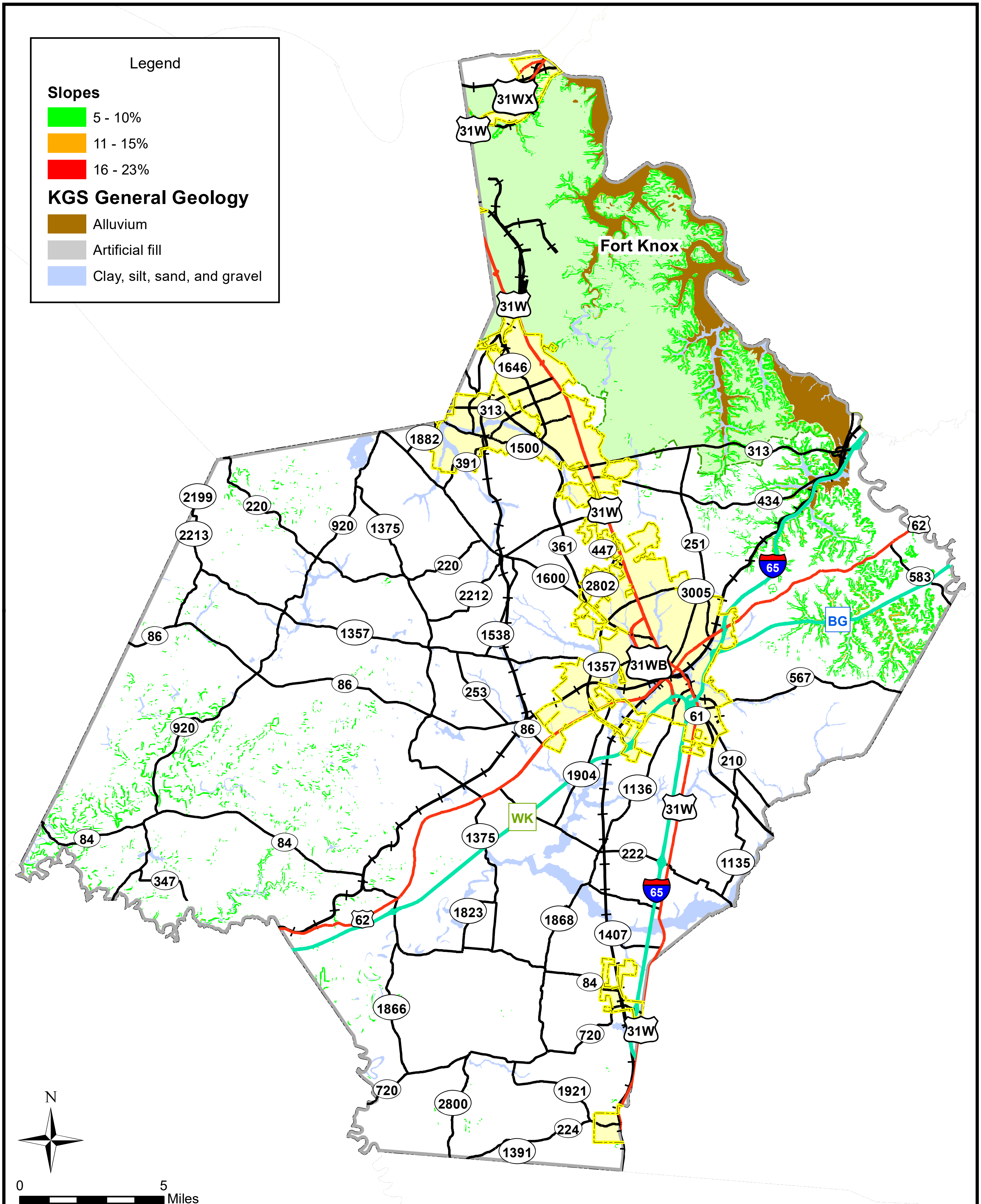
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2213
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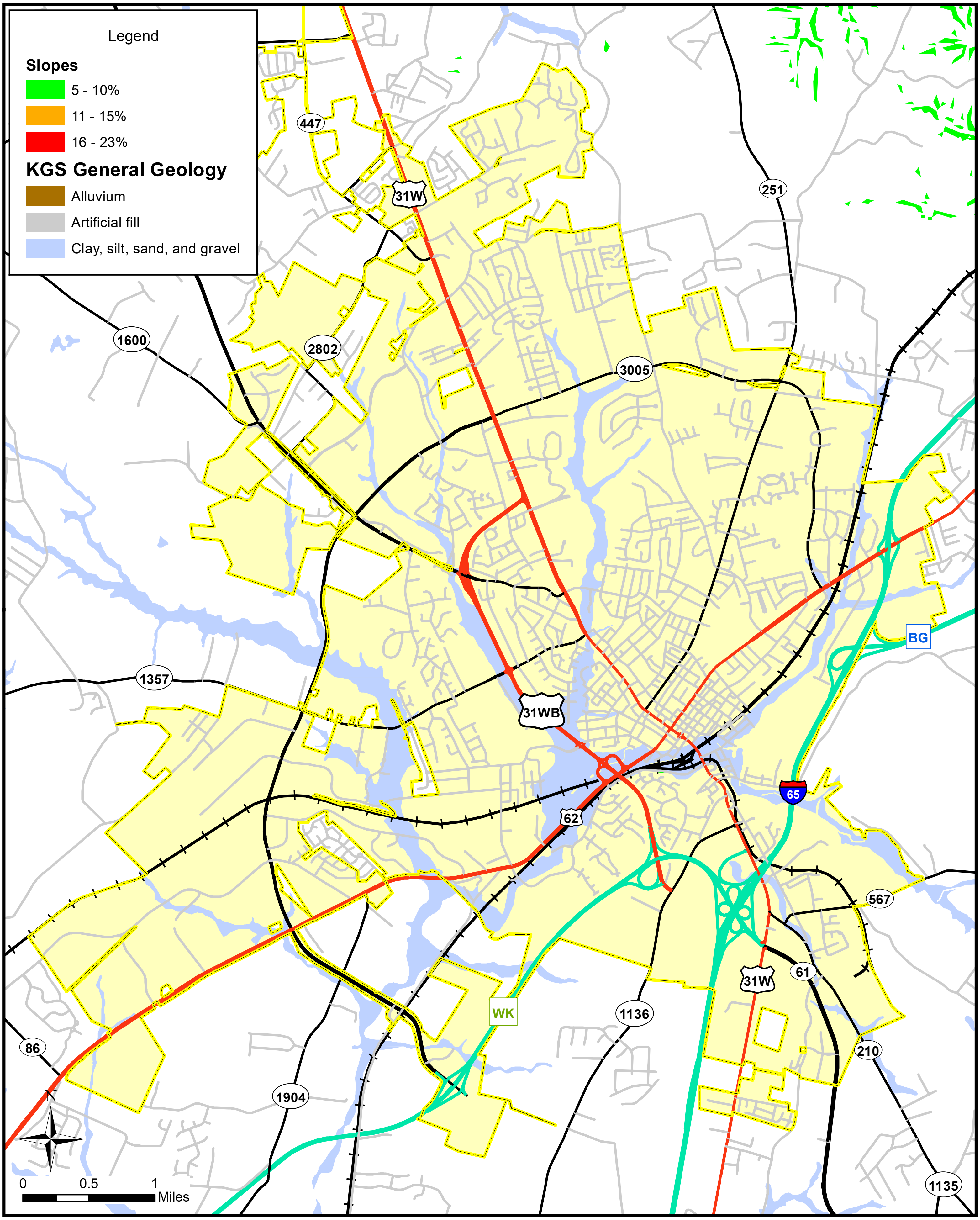
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Artificial fill
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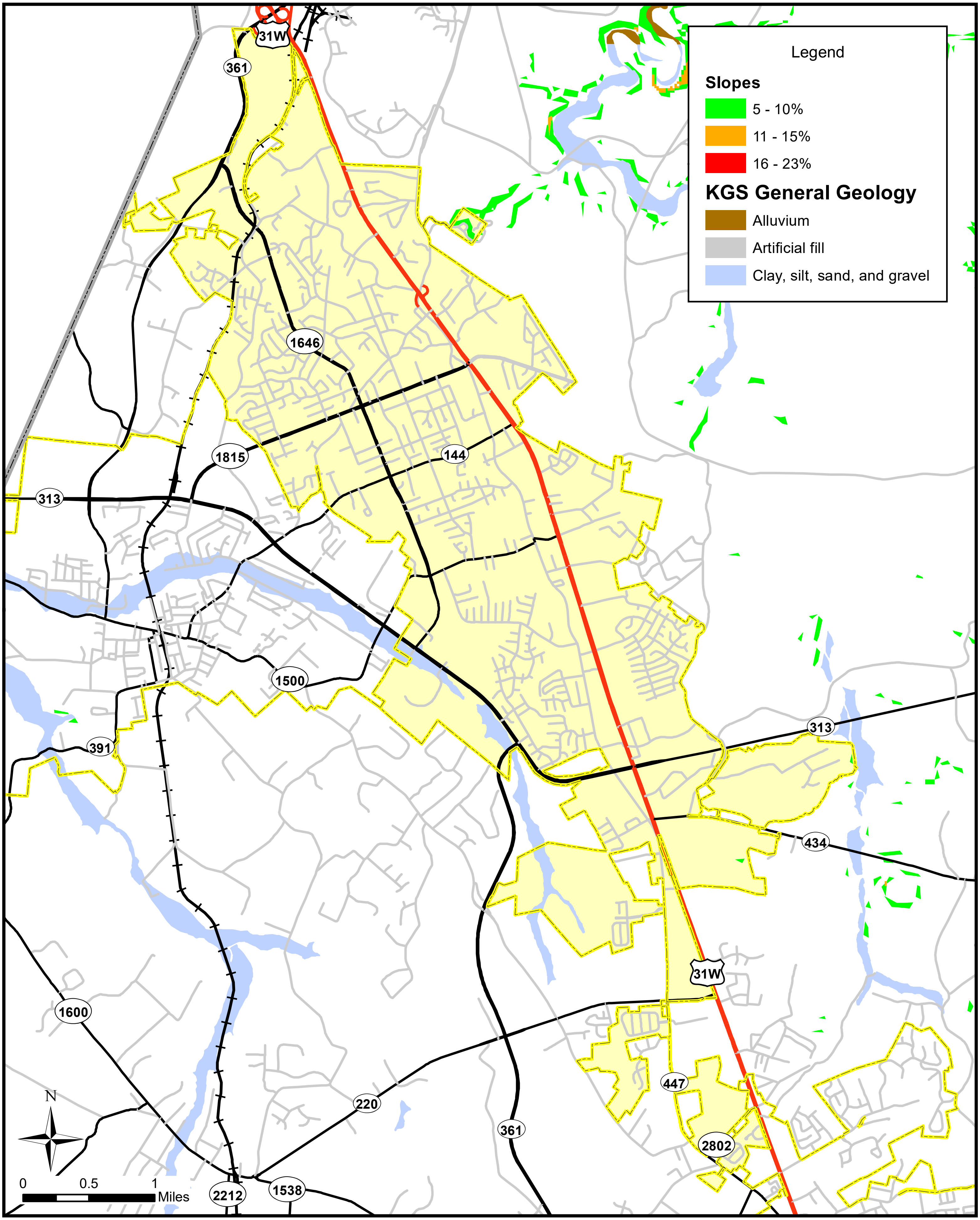
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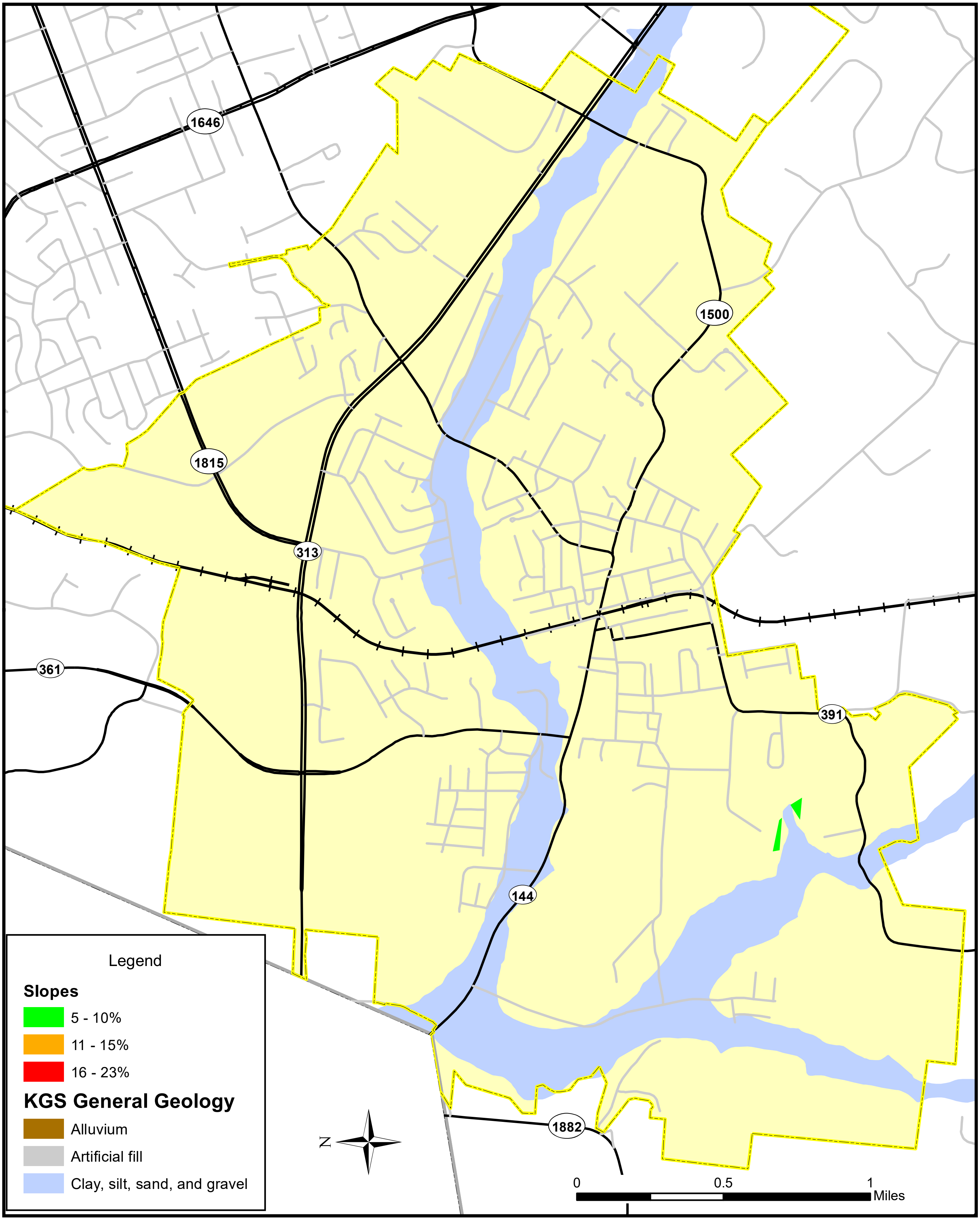
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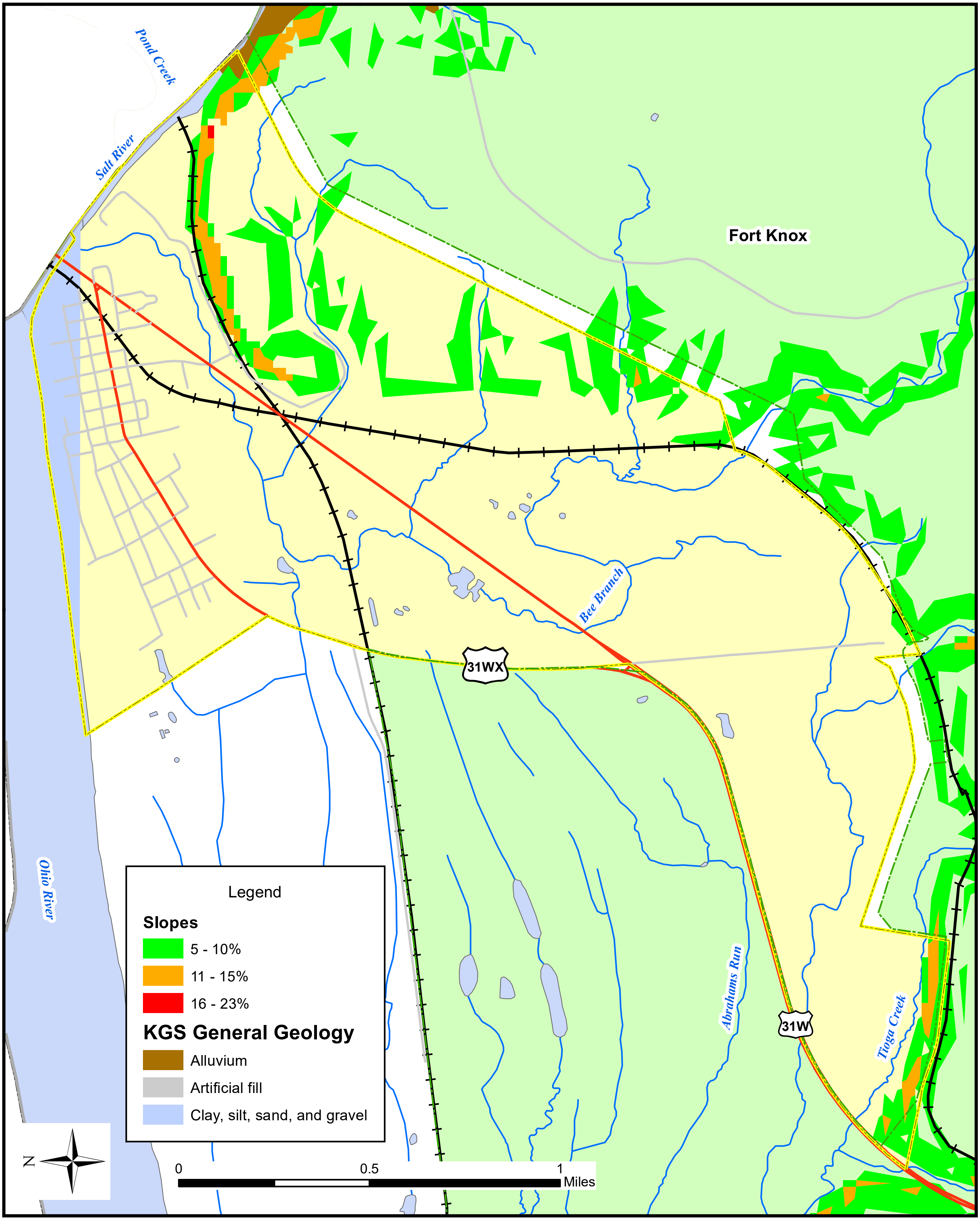
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Fort Knox
Bee Branch
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31W
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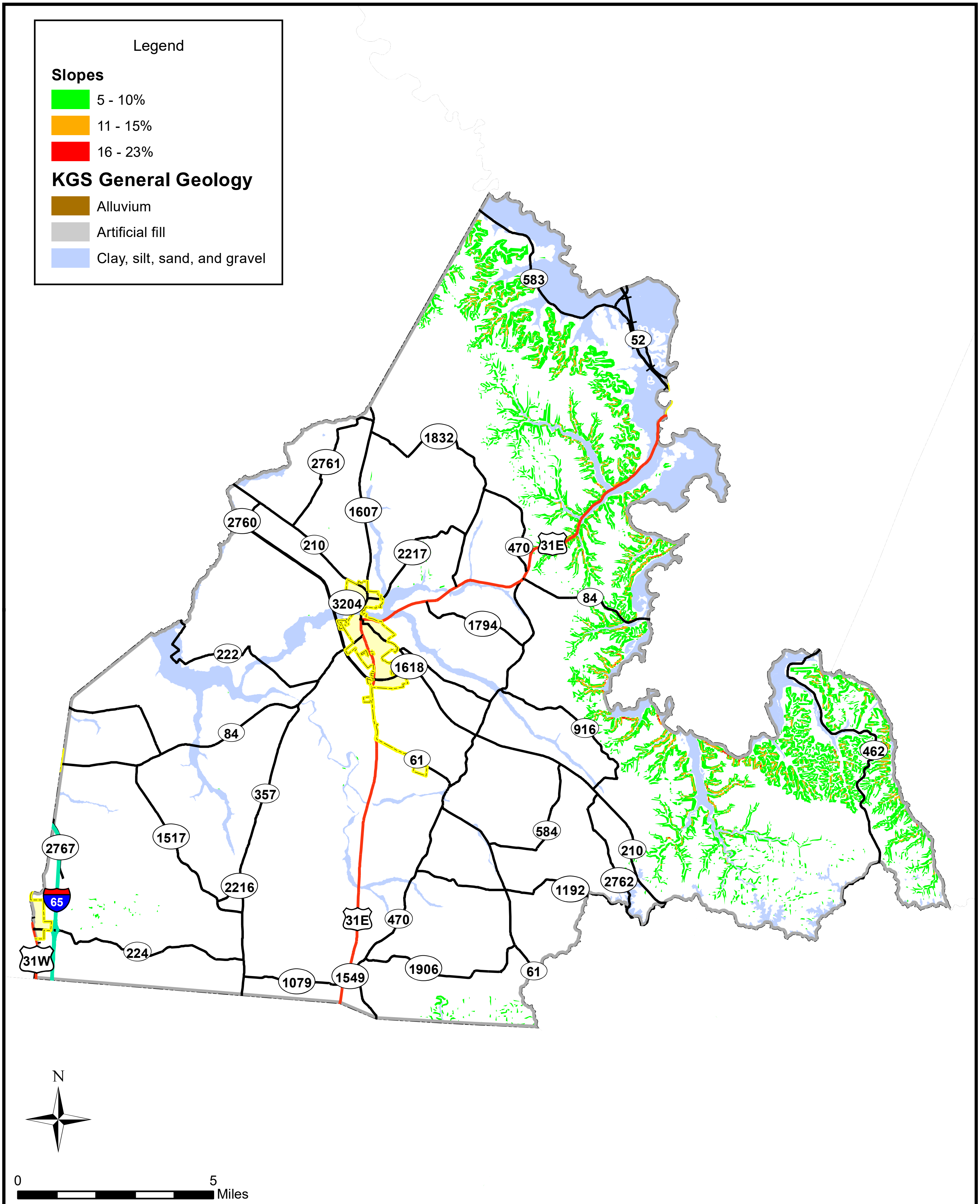
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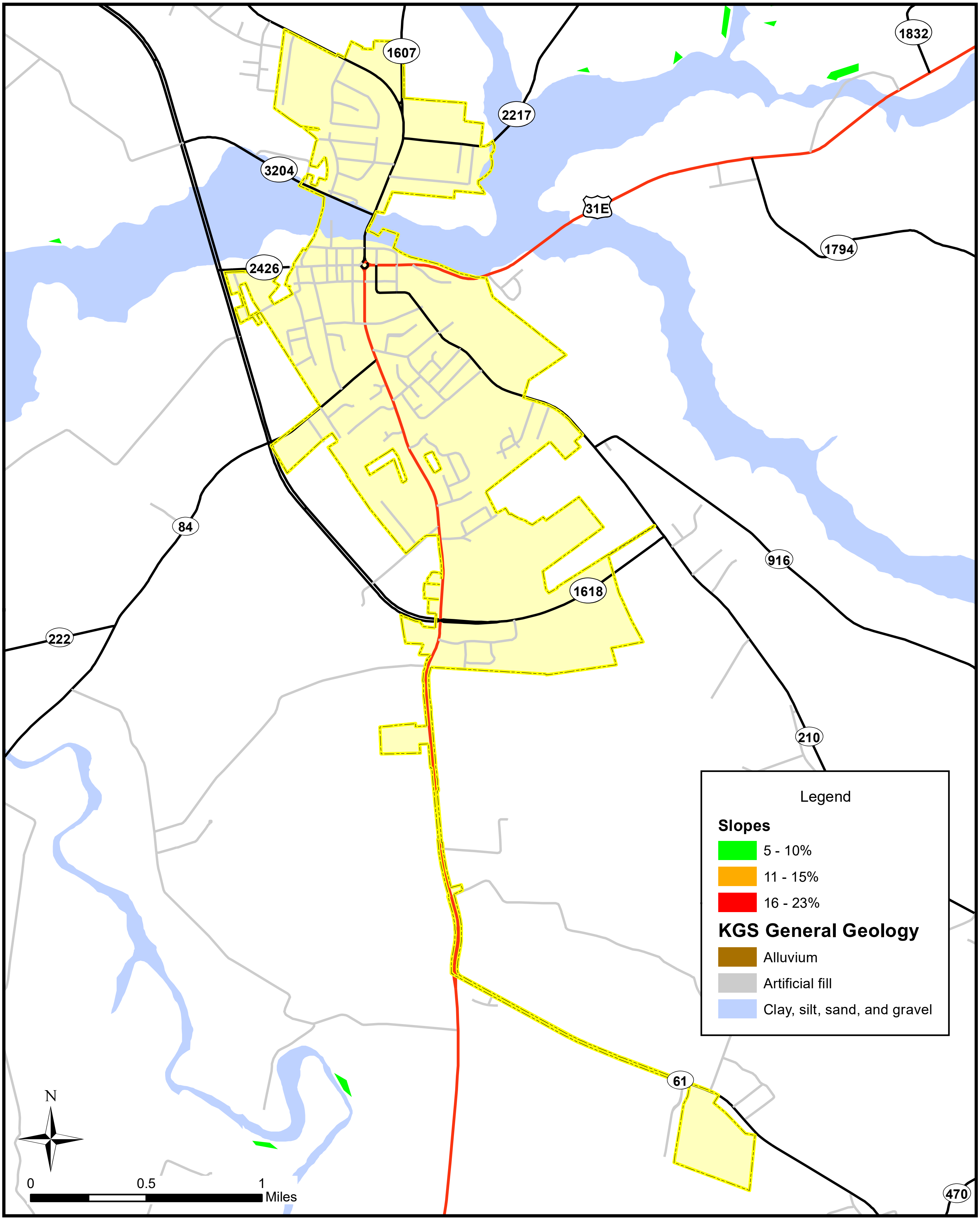
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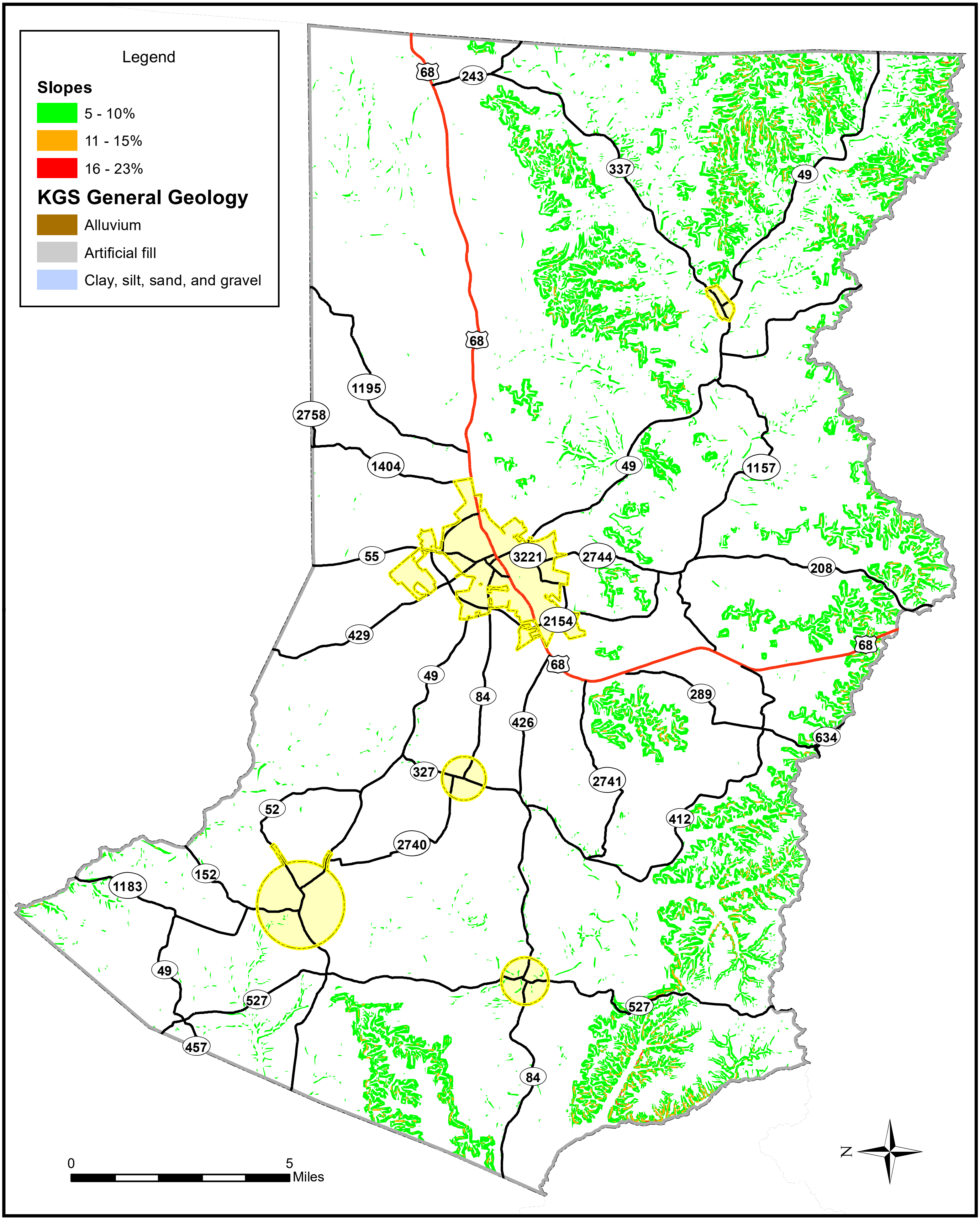
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68
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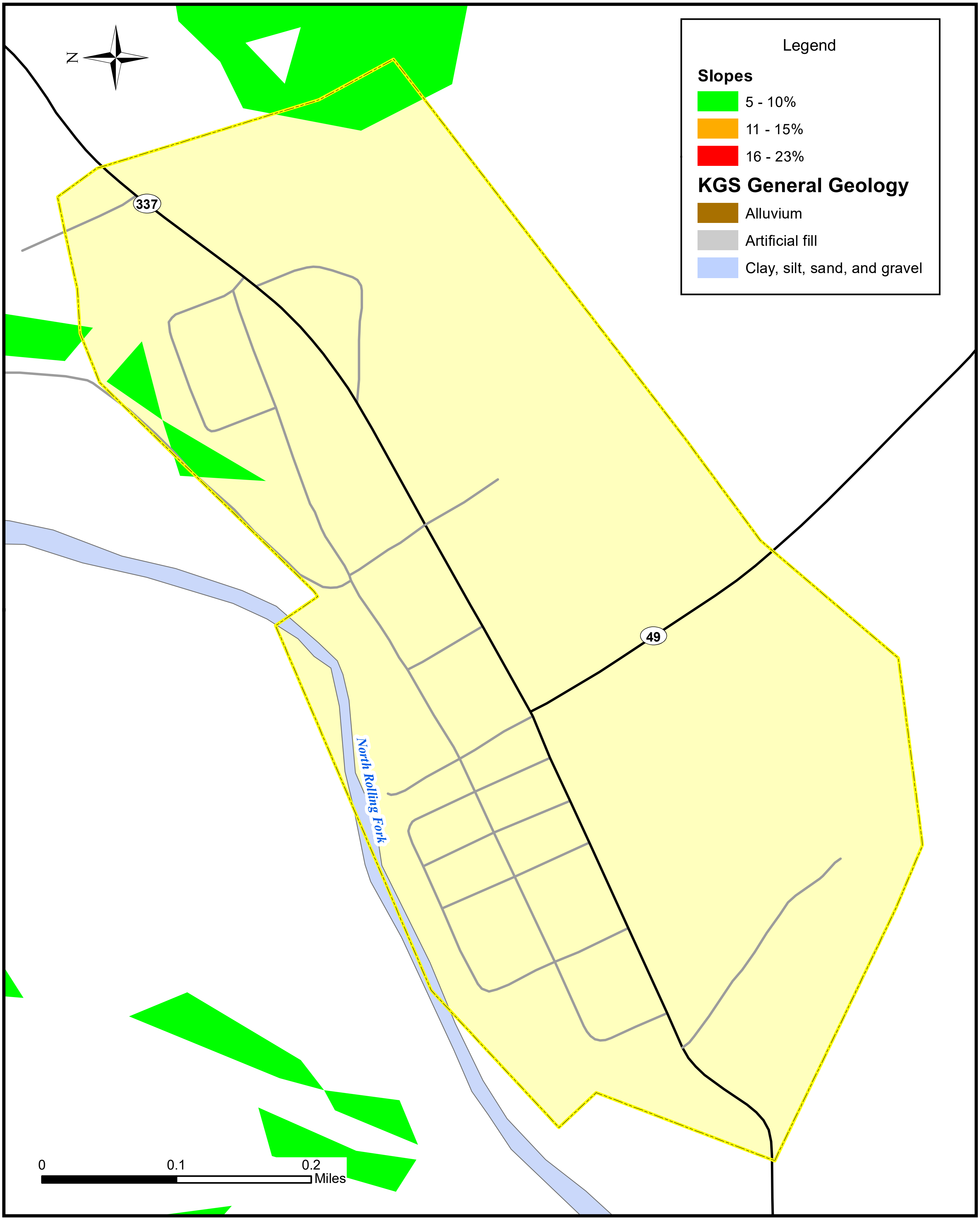
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Clay, silt, sand, and gravel
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North Rolling Fork
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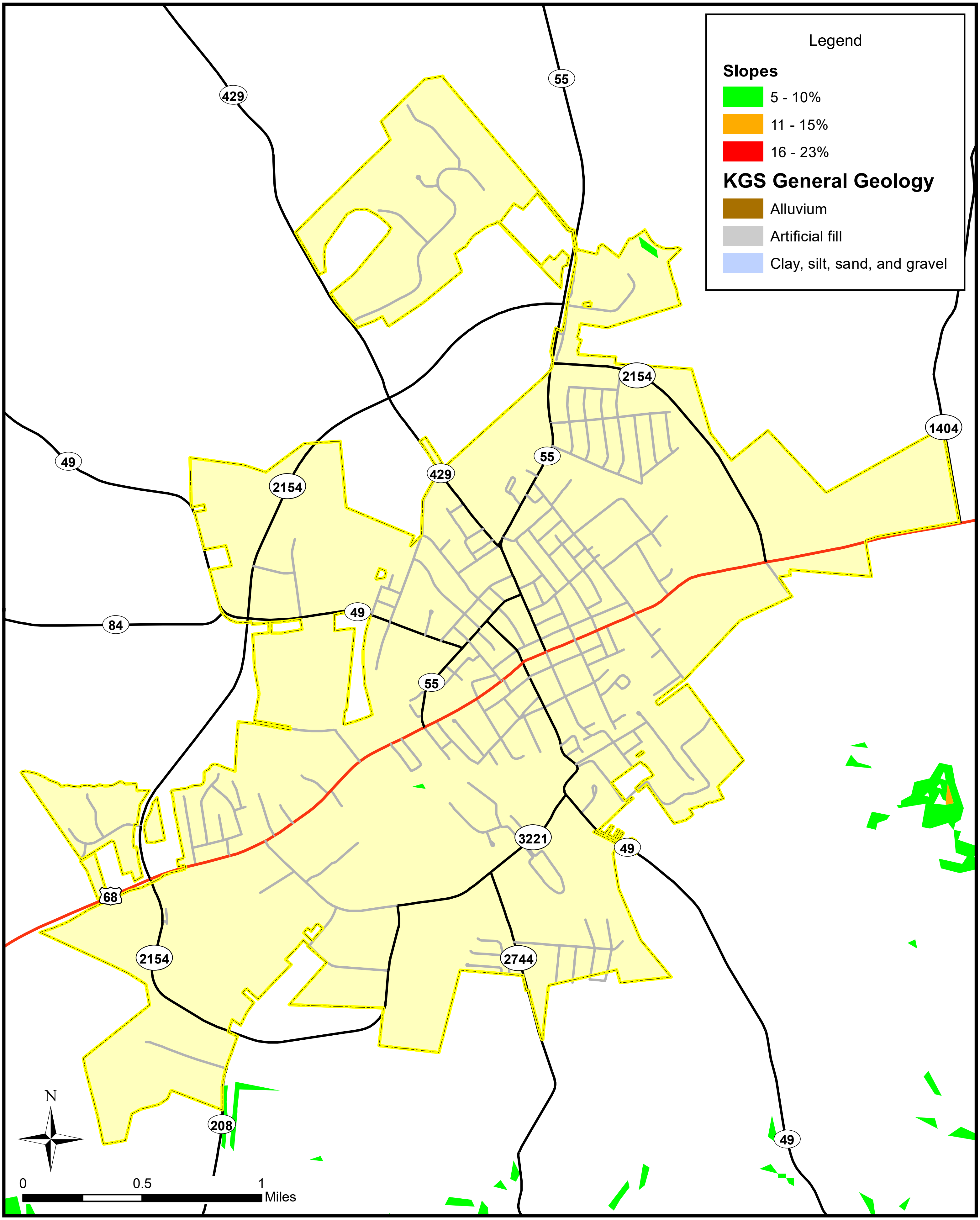
Miles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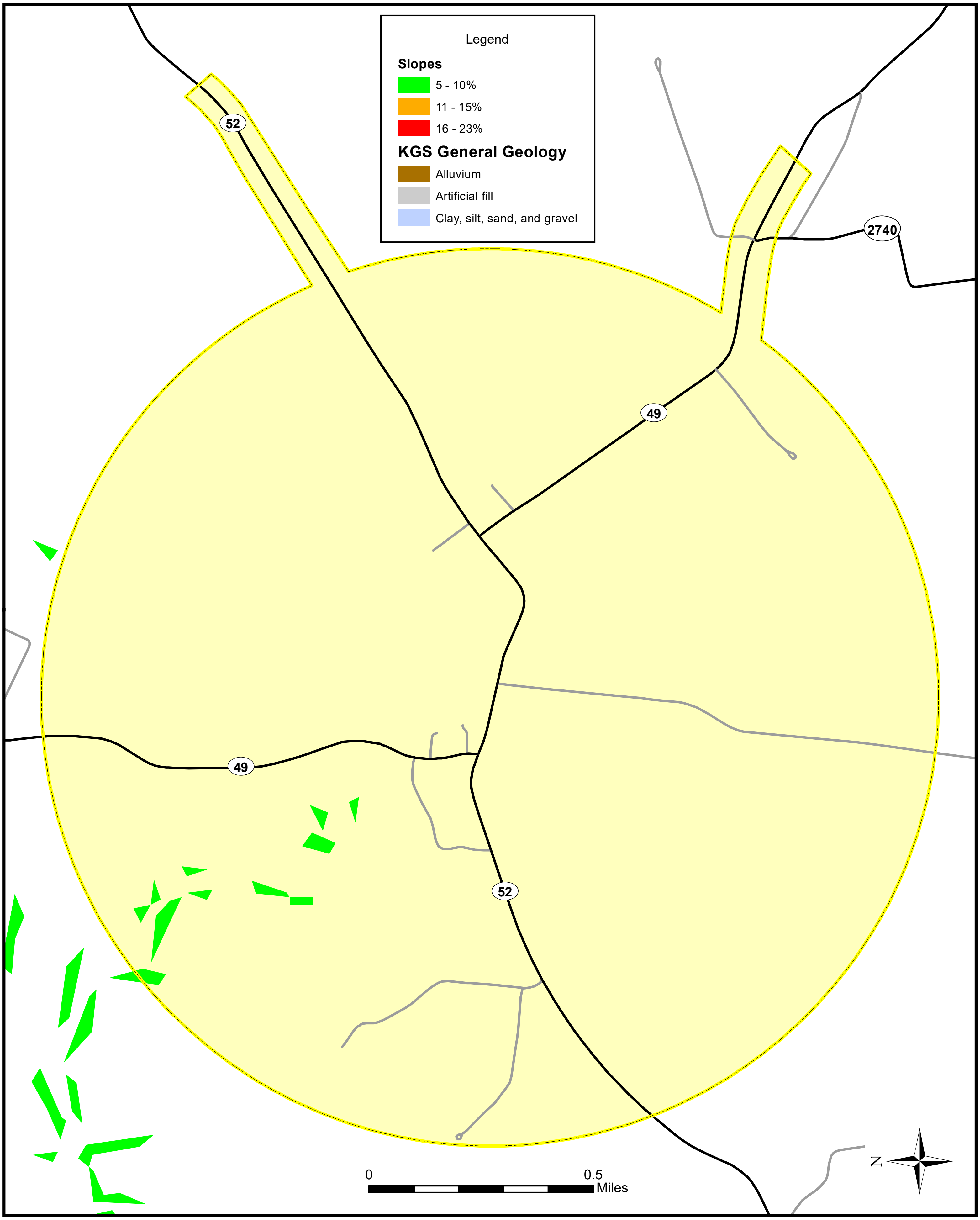
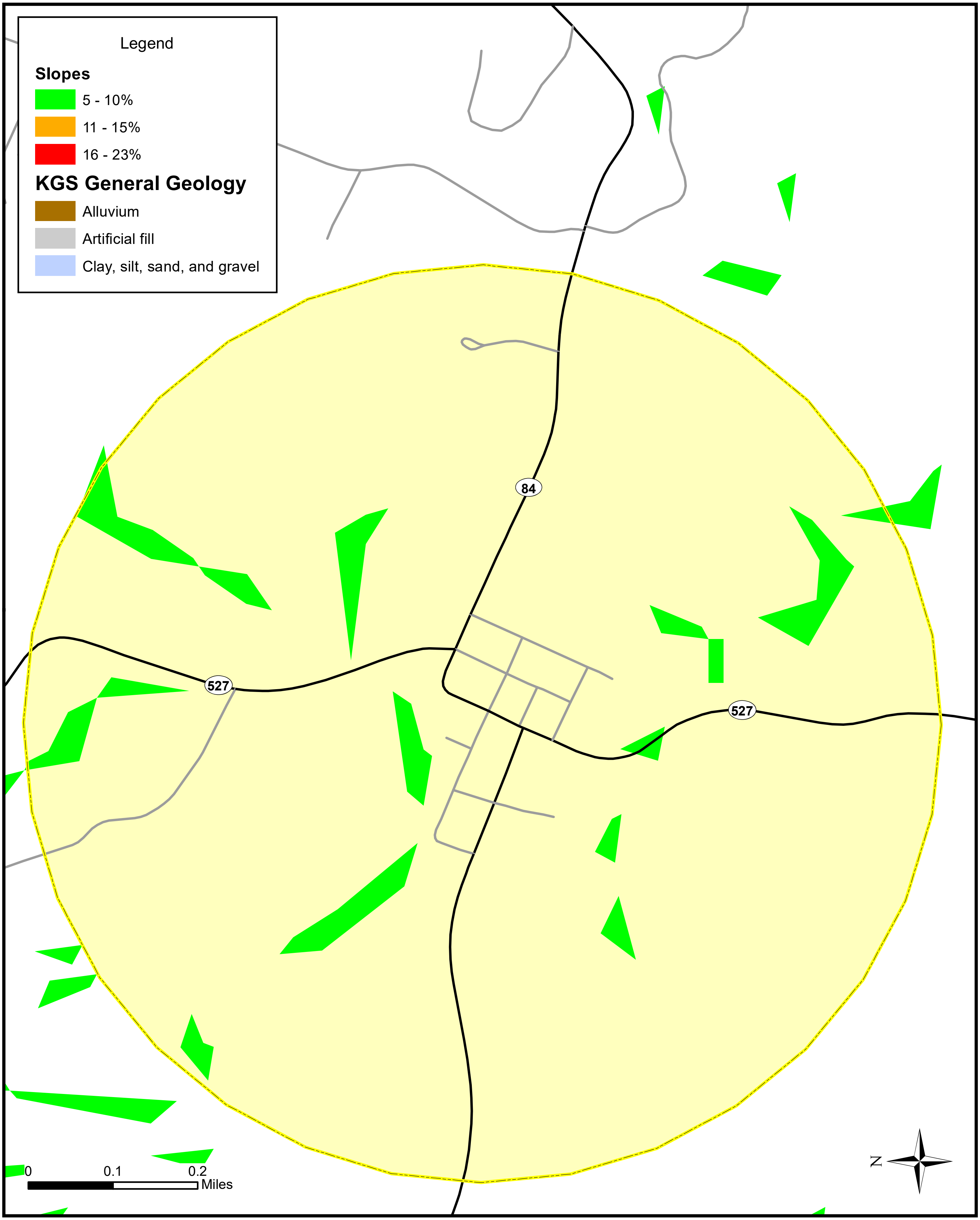
Miles

LORETTO
LANDSLIDE

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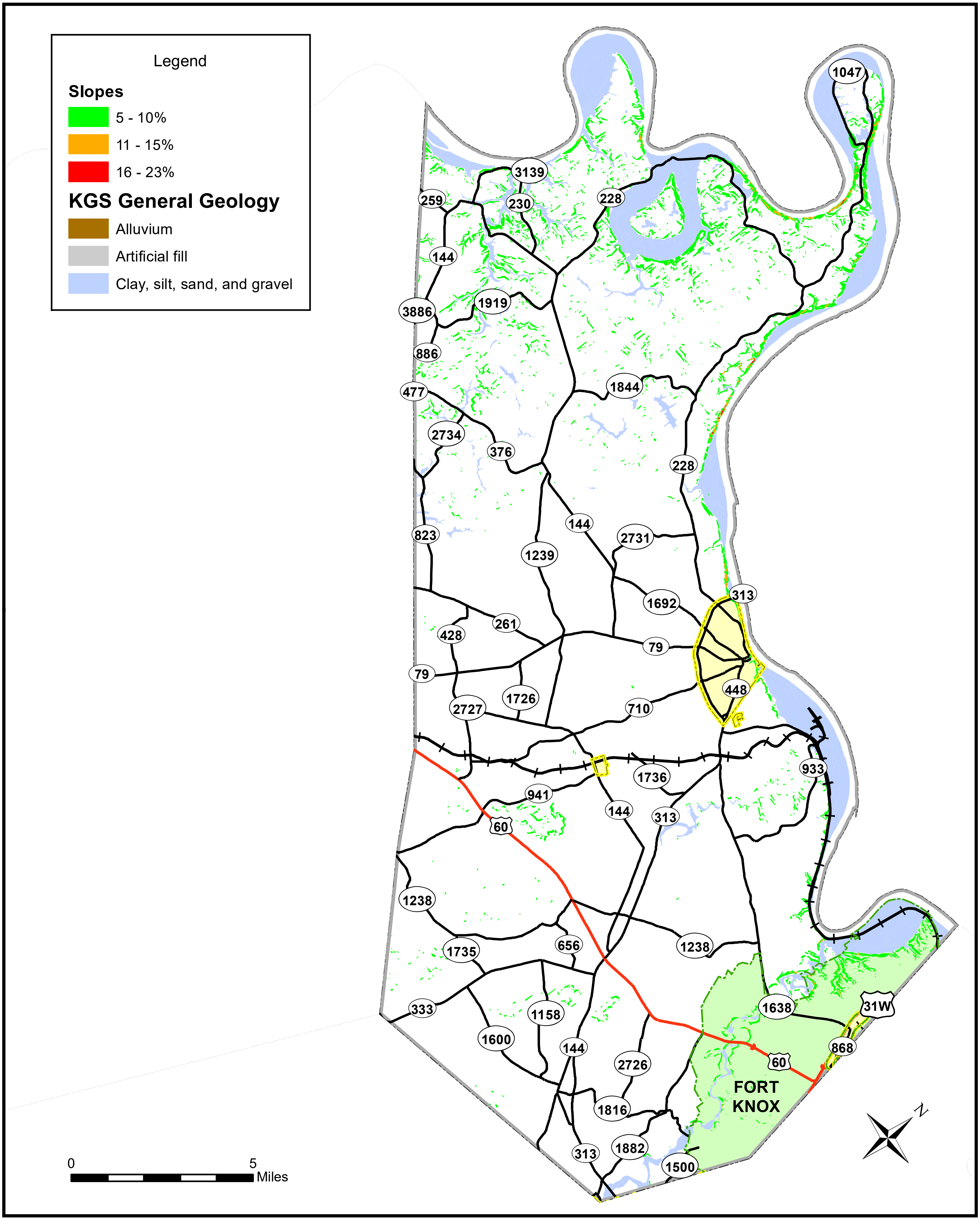
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31W
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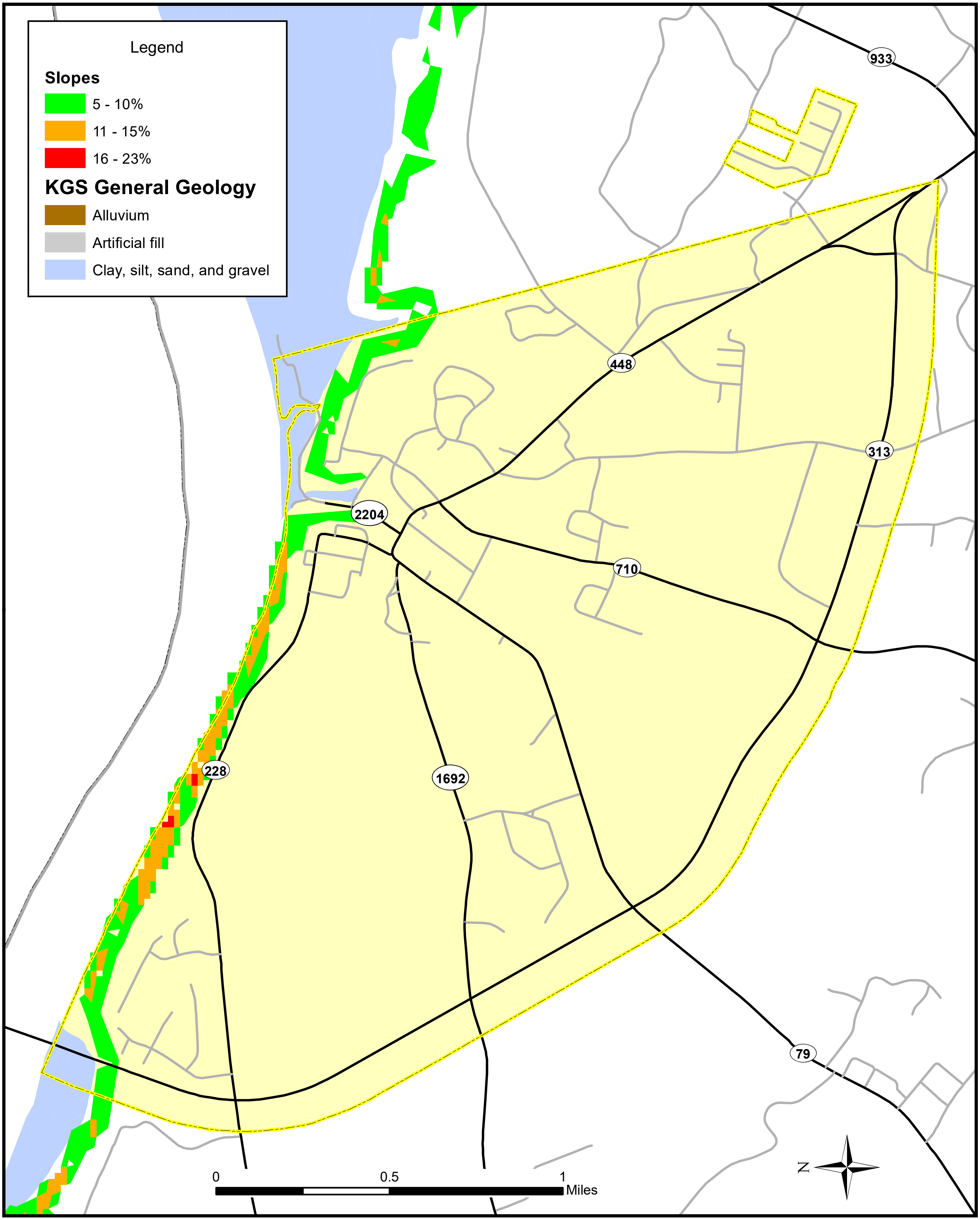
Miles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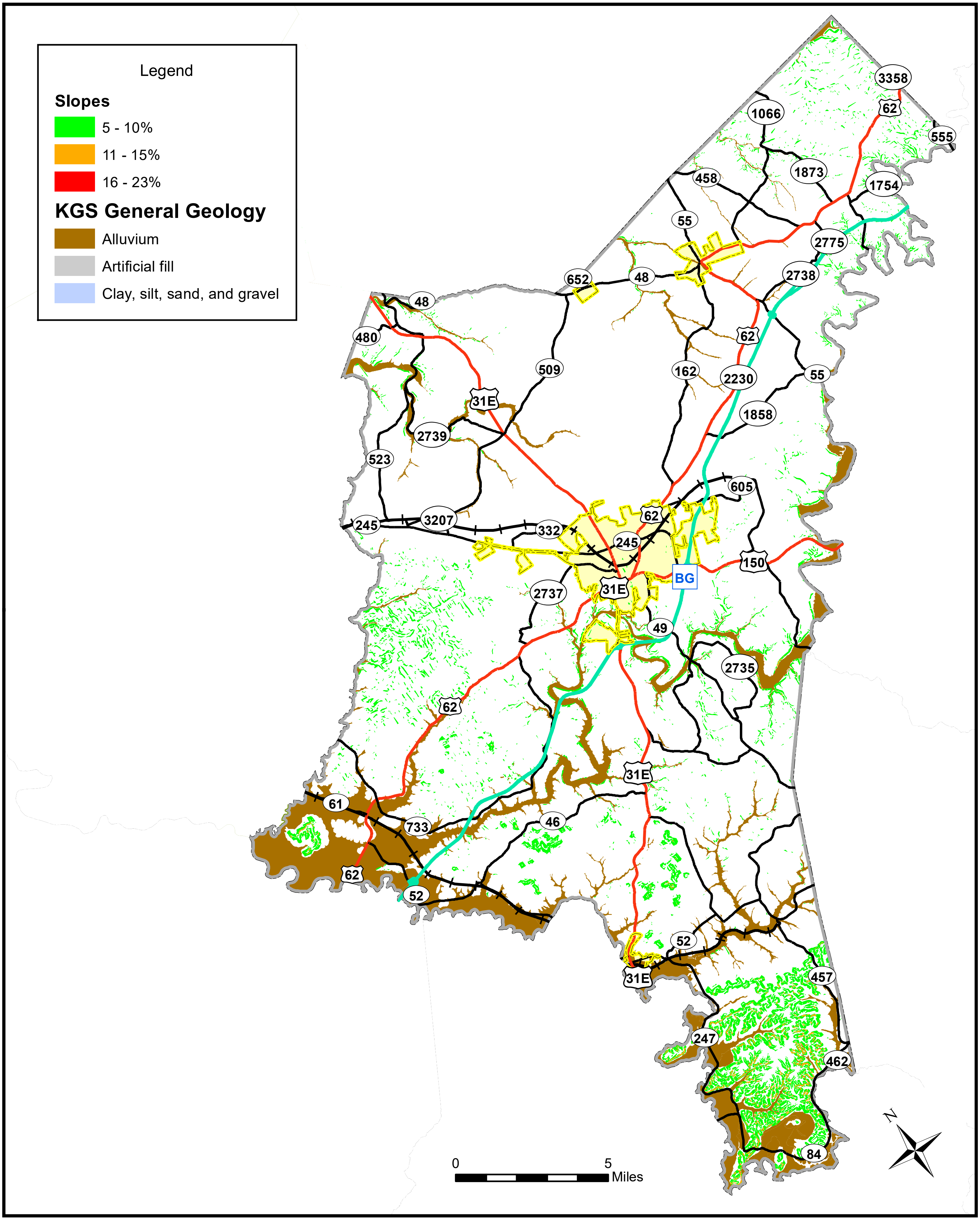
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Alluvium
Artificial fill
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0
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Miles
BG
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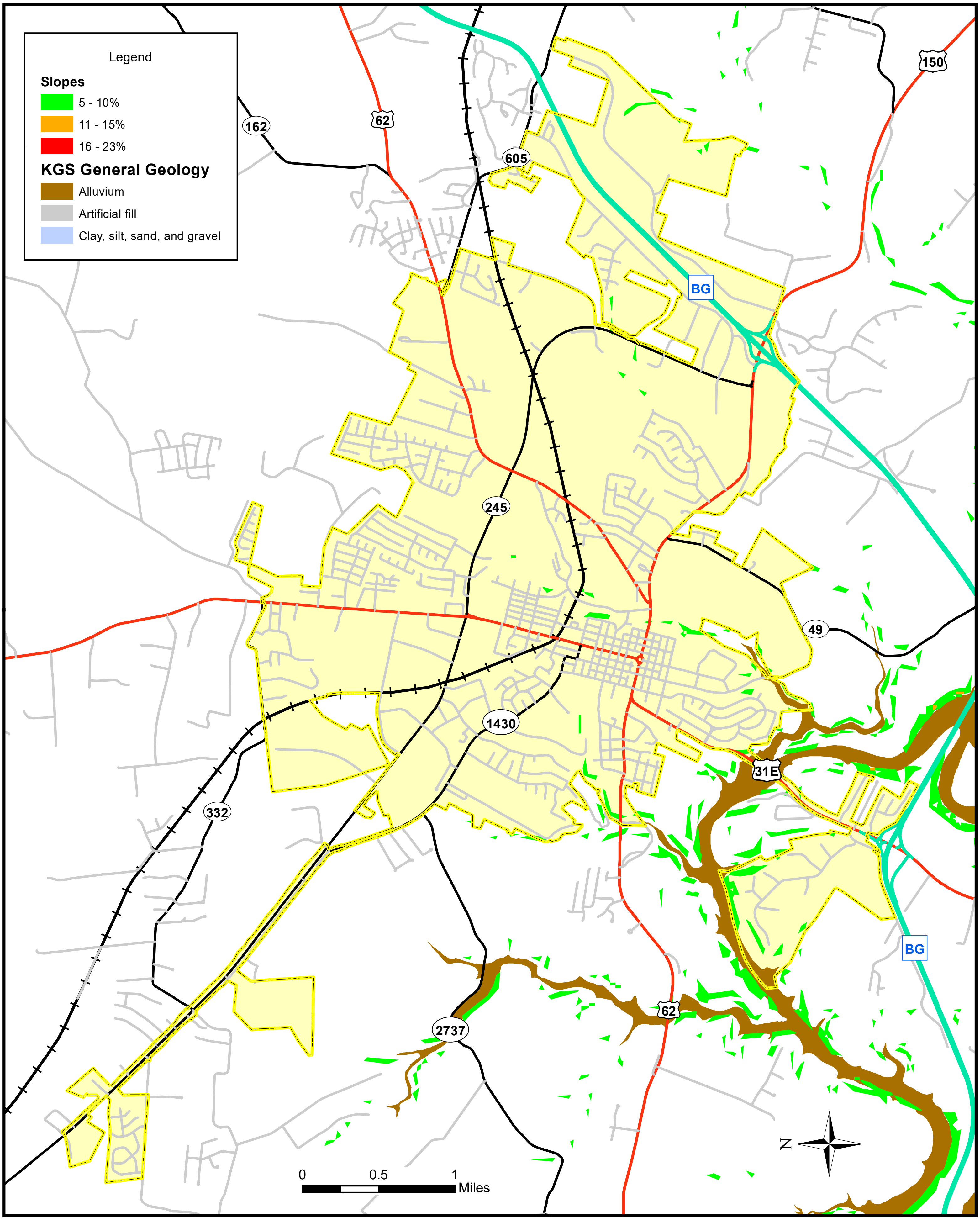
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Artificial fill
Clay, silt, sand, and gravel
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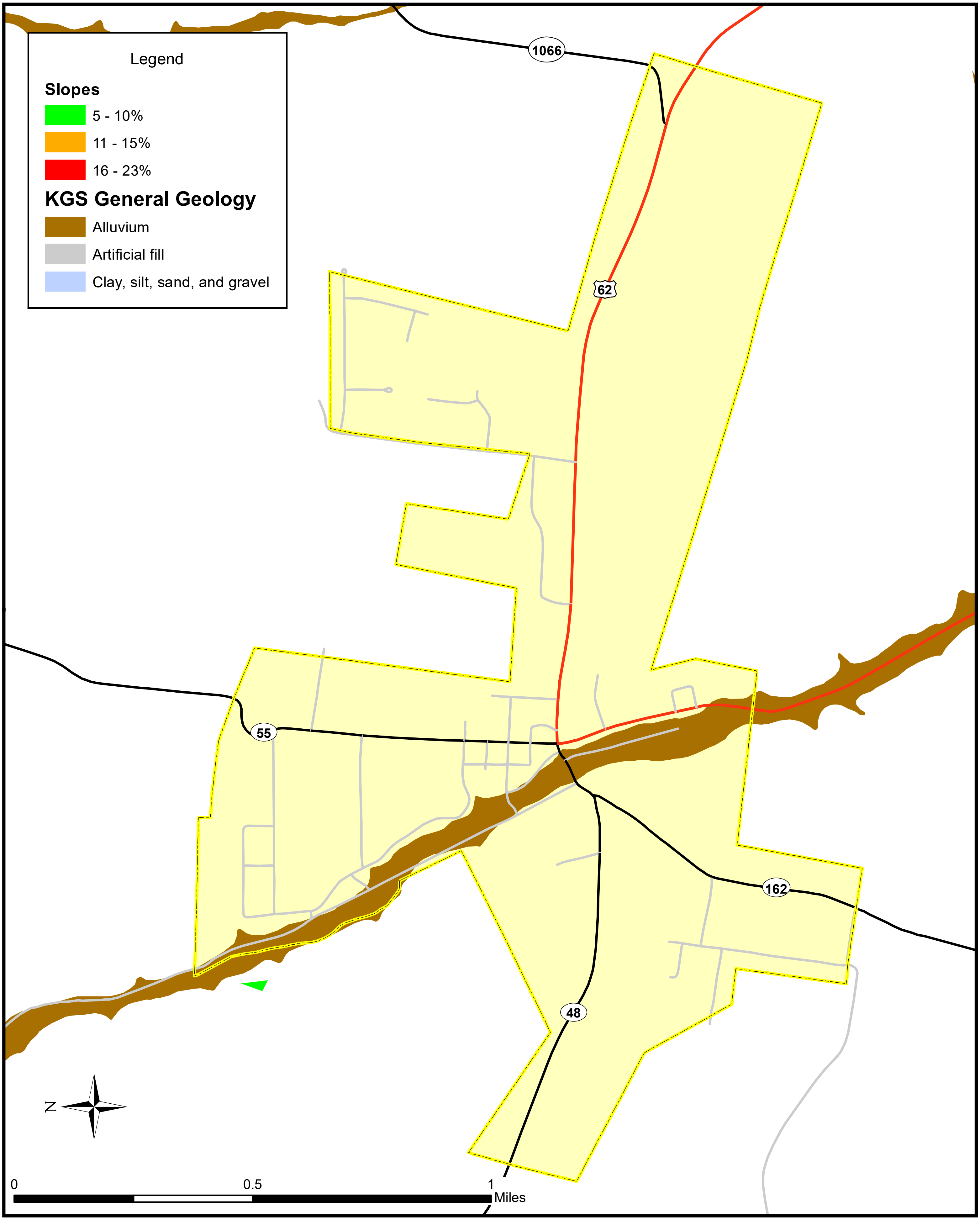
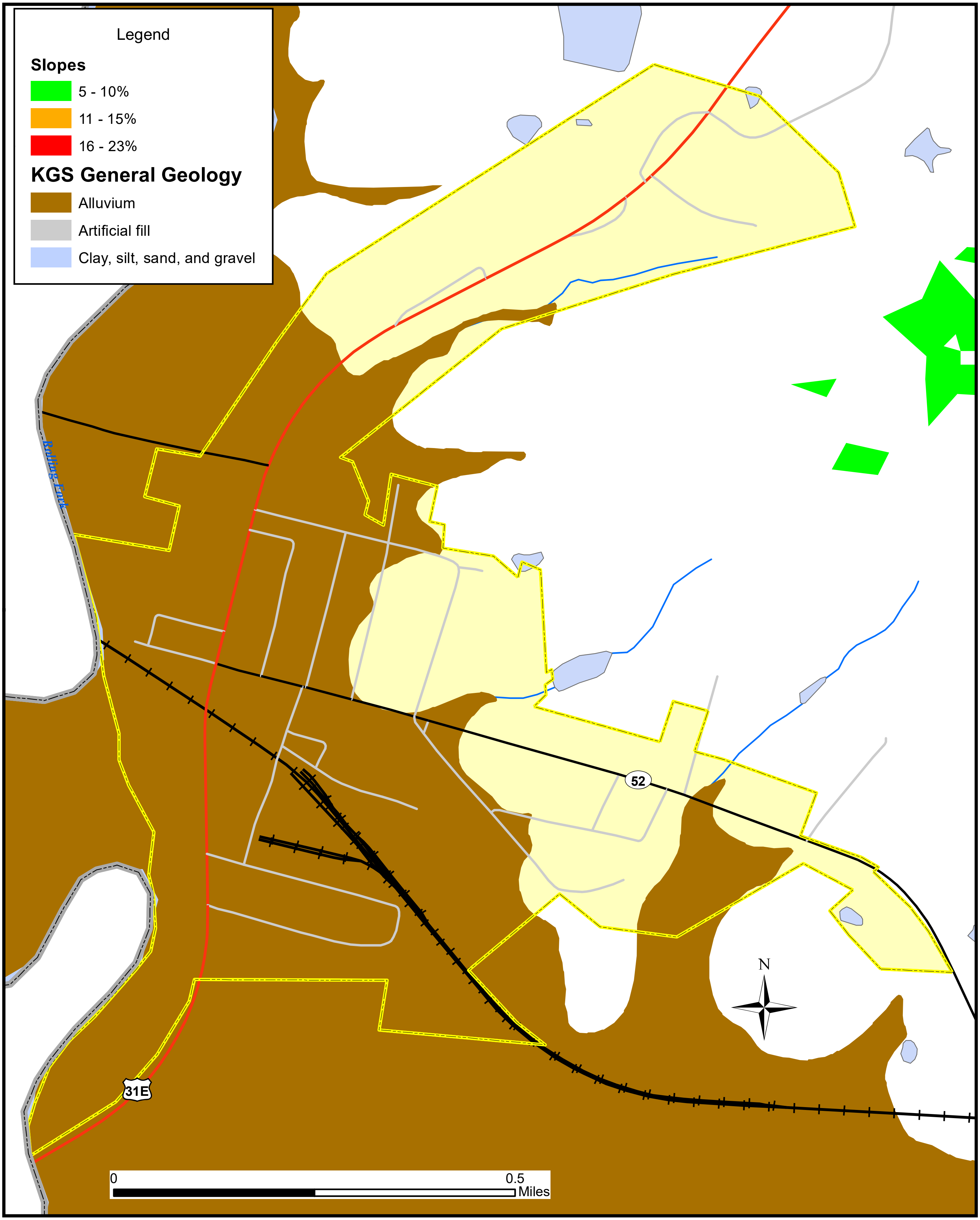
BLOOMFIELD
LANDSLIDE

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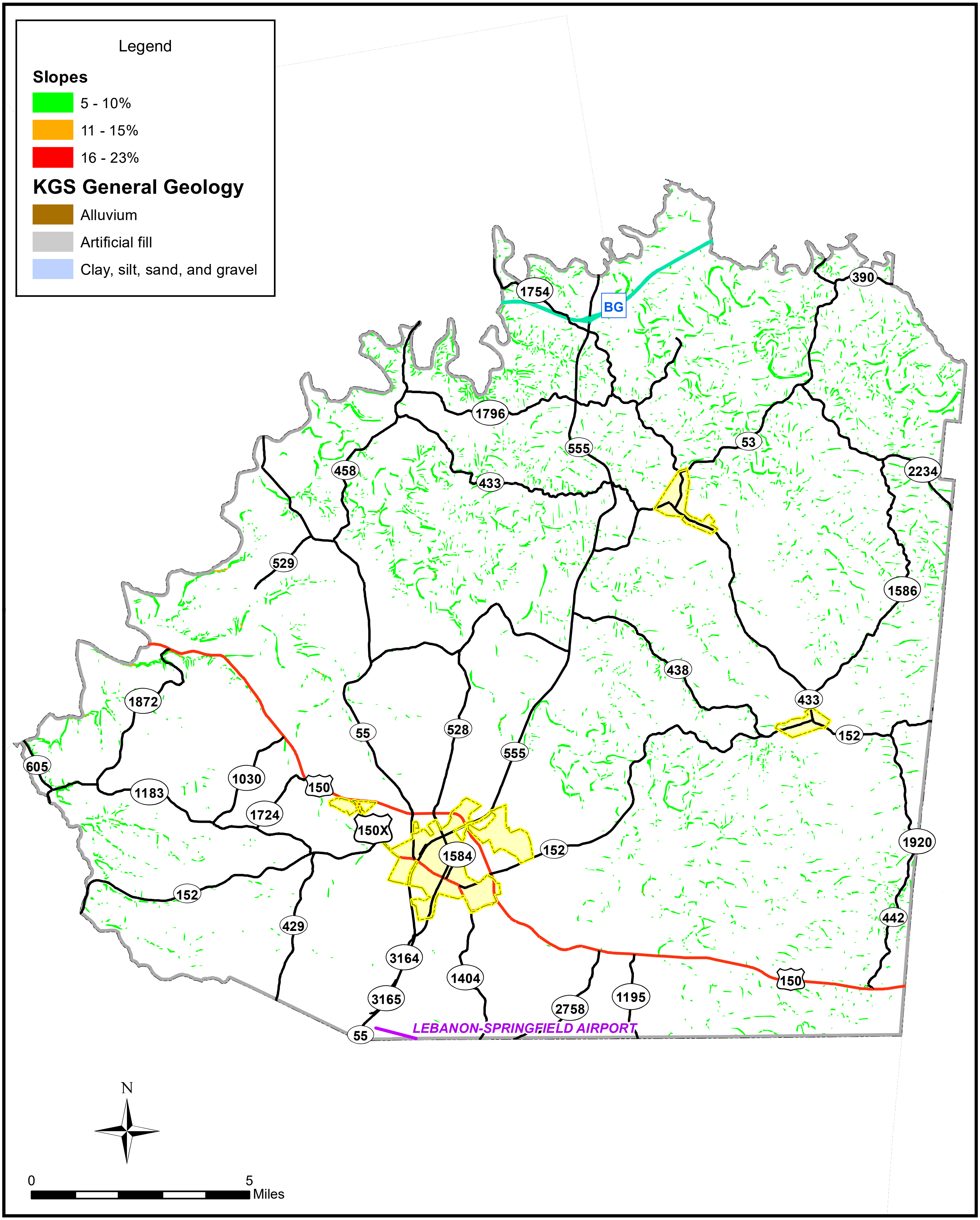
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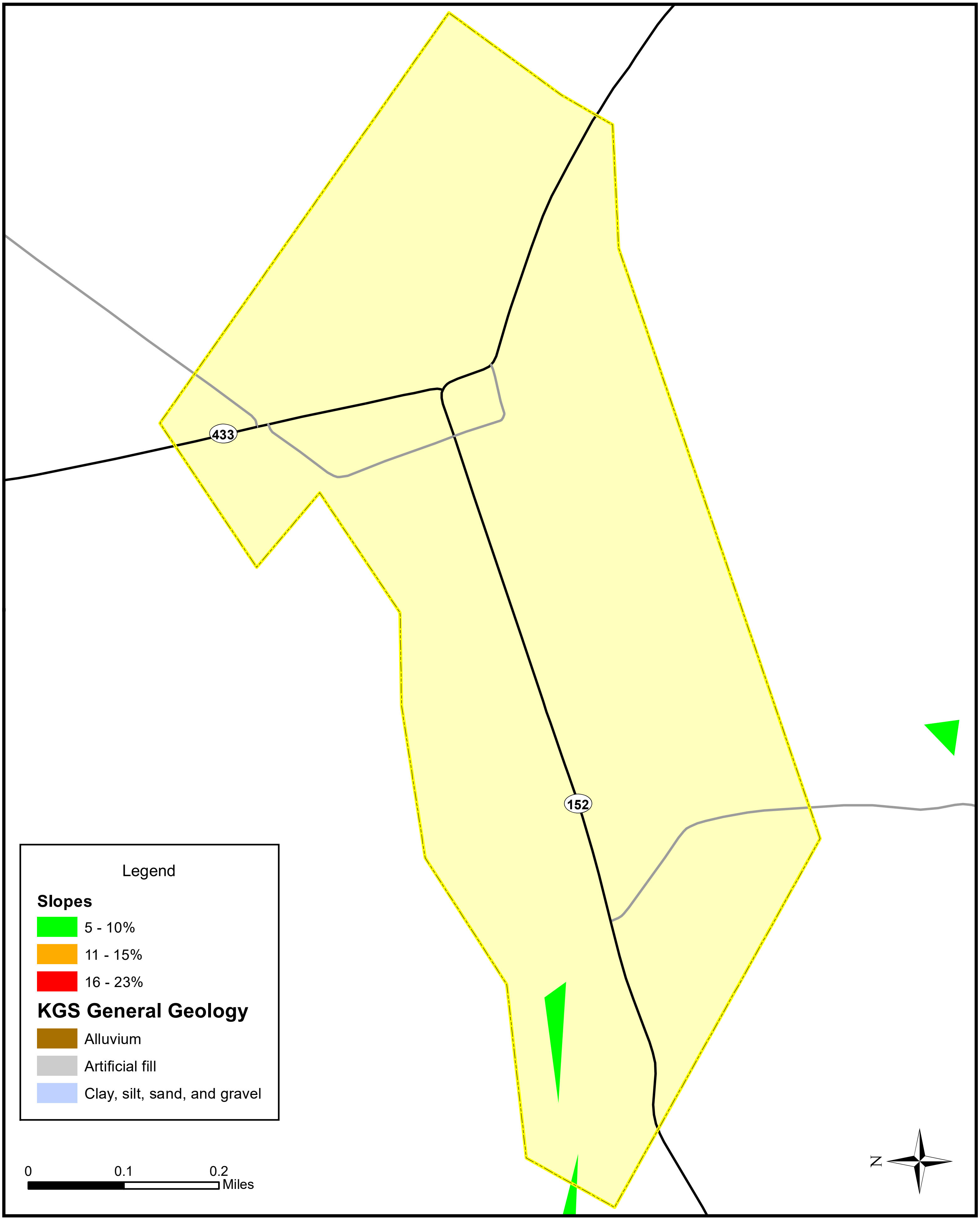
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Slopes
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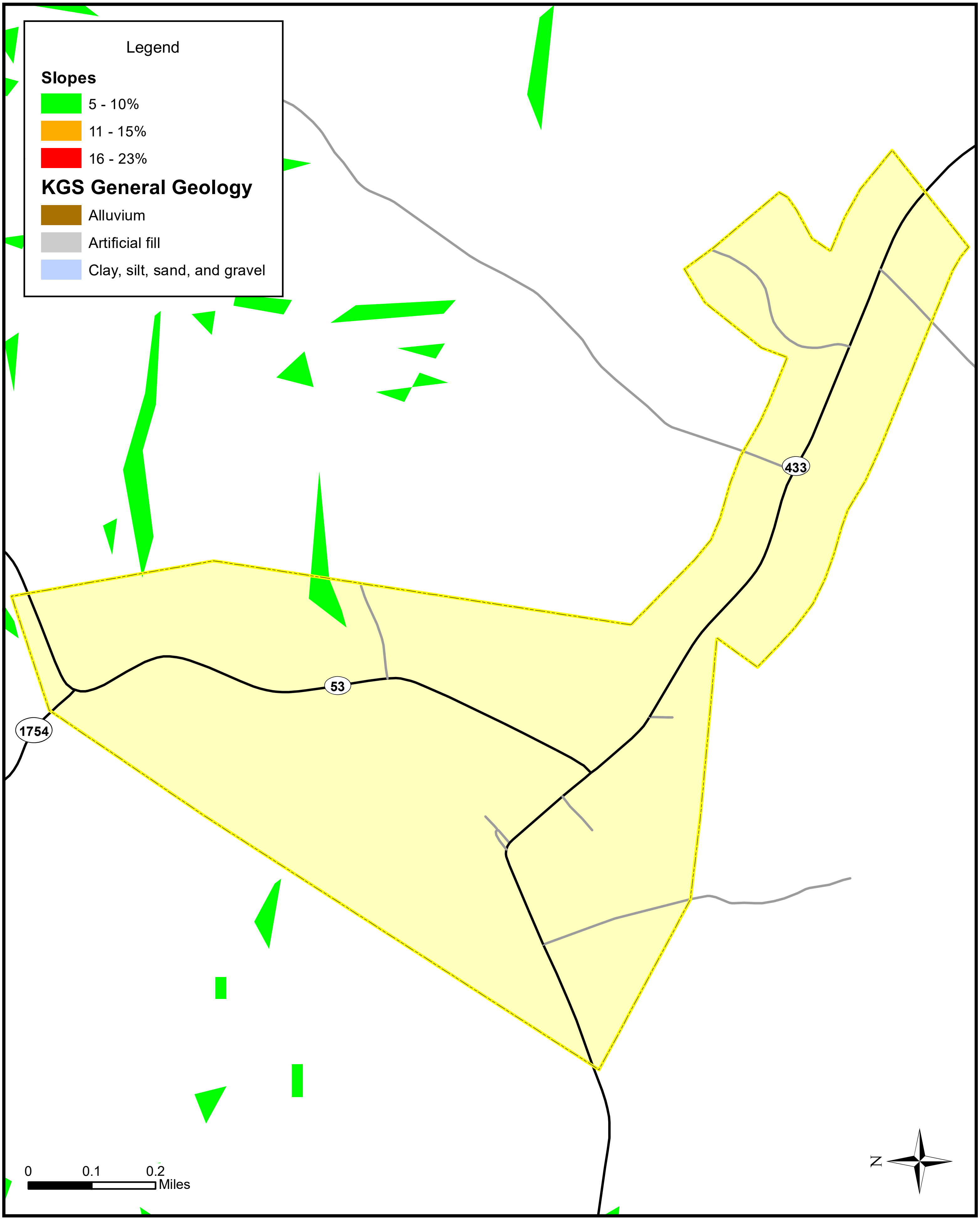
Legend
Slopes
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11 - 15%
16 - 23%
KGS General Geology
Alluvium
Artificial fill
Clay, silt, sand, and gravel
433
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1754
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0.2
Miles
N

3.3.2.8 <u>Karst/Sinkhole</u>

I. Background

Karst Topography:

According to the *Encyclopedia Britannica,* karst topography is characterized by barren, rocky ground, caves, sinkholes, underground rivers, and the absence of surface streams and lakes. This type of landscape results from the excavating effects of underground water movement on massive soluble limestone. While the term *Karst* originally was applied to a region of limestone on the Dalmatian coast of the Adriatic Sea, it has now been extended to mean all areas with similar features.

Karsts are found in widely scattered regions of the world such as the Causes of France; the Kwangsi area of China; the Yucatan Peninsula; and the Middle East, they are also found in Kentucky, Texas, Tennessee, Missouri, Pennsylvania, and Florida in the United States. Although the karst topography in Kentucky is mostly on limestone, it can also occur in different types of rock such as dolomite, gypsum, and salt.

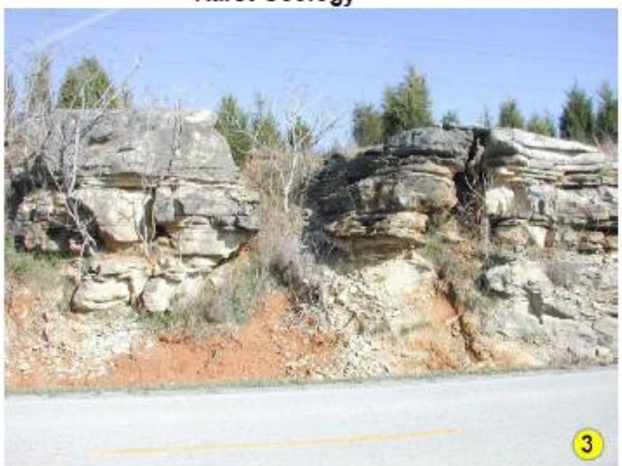
Certain conditions promote karst development such as well-jointed, dense limestone near the ground surface, a moderate to heavy rainfall, and good groundwater circulation. Limestone or calcium carbonate is easily dissolved by slightly acidic water, which occurs widely in nature. Rain becomes slightly acidic as it passes through the air and picks up carbon dioxide (CO_2). Rainwater percolates along both horizontal and vertical cracks, dissolving the limestone and carrying it away in solution. Limestone pavements are produced when surface material is removed, and the vertical fissures along joints gradually widen and deepen, producing a grooved and jagged terrain. As the water continues to flow underground, it widens and deepens the cracks until they become cave systems or underground stream channels. All but a few of the cave areas in the world are areas of karst topography. A karst landscape is characterized by sinkholes, sinking streams, caves, and springs.

Kentucky is one of the most famous karst areas in the world. Much of the beautiful scenery throughout Kentucky is the result of the development of karst landscape. The springs and wells inherent to karst landscape, provide water to many Kentucky cities. About fifty-five percent of Kentucky is underlain by rocks that could develop karst, given enough time, and about thirty-eight percent of the state has some karst development. Twenty-five percent of the state is known to have well-developed karst features. Karst topography forms the world's longest cave system; the Mammoth Cave System in Kentucky is over 350 miles long.

Karst topography is found throughout the Lincoln Trail ADD region. Parts of Meade and Breckinridge Counties, in the vicinity of Irvington and Brandenburg have extensive areas of karst topography that can be seen by driving the roadways through these communities. Saunders Springs Nature Preserve in the Fort Knox Military Reservation just west of Radcliff is an excellent example of karst topography. In addition, many large springs can be found west of Fort Knox in Meade and Breckinridge Counties. There are springs and caves within Otter Creek Park in Meade

County and a spring at the Lincoln Birthplace National Historic Site in LaRue County called Sinking Spring.

Karst Geology



This old roadcut in the Salem Limestone (unit 2) reveals the dissolution process that creates underground cavities and, when the cavity roofs collapse, sinkholes. Photo by Dan Carey, Kentucky Geological Survey.

Limestone formation in Meade County, 2005.

Sinkholes

When a cave becomes large enough and its top extends close enough to the surface, the top collapses. This produces depressions called sinkholes. Sinkholes are characteristic features of karst topography. Sinkholes can coalesce into larger depressions called polje. Sinkholes collect surface water running off the surrounding land, and the runoff goes directly into the groundwater. A sinkhole is an area of ground that has no natural external surface drainage. When it rains, water stays inside the sinkhole and usually drains into the subsurface. Sinkholes vary in size from a few feet to hundreds of acres, and range in depth from between one foot to several hundred feet. Some sinkholes hold water to form natural ponds.

Types of Sinkholes

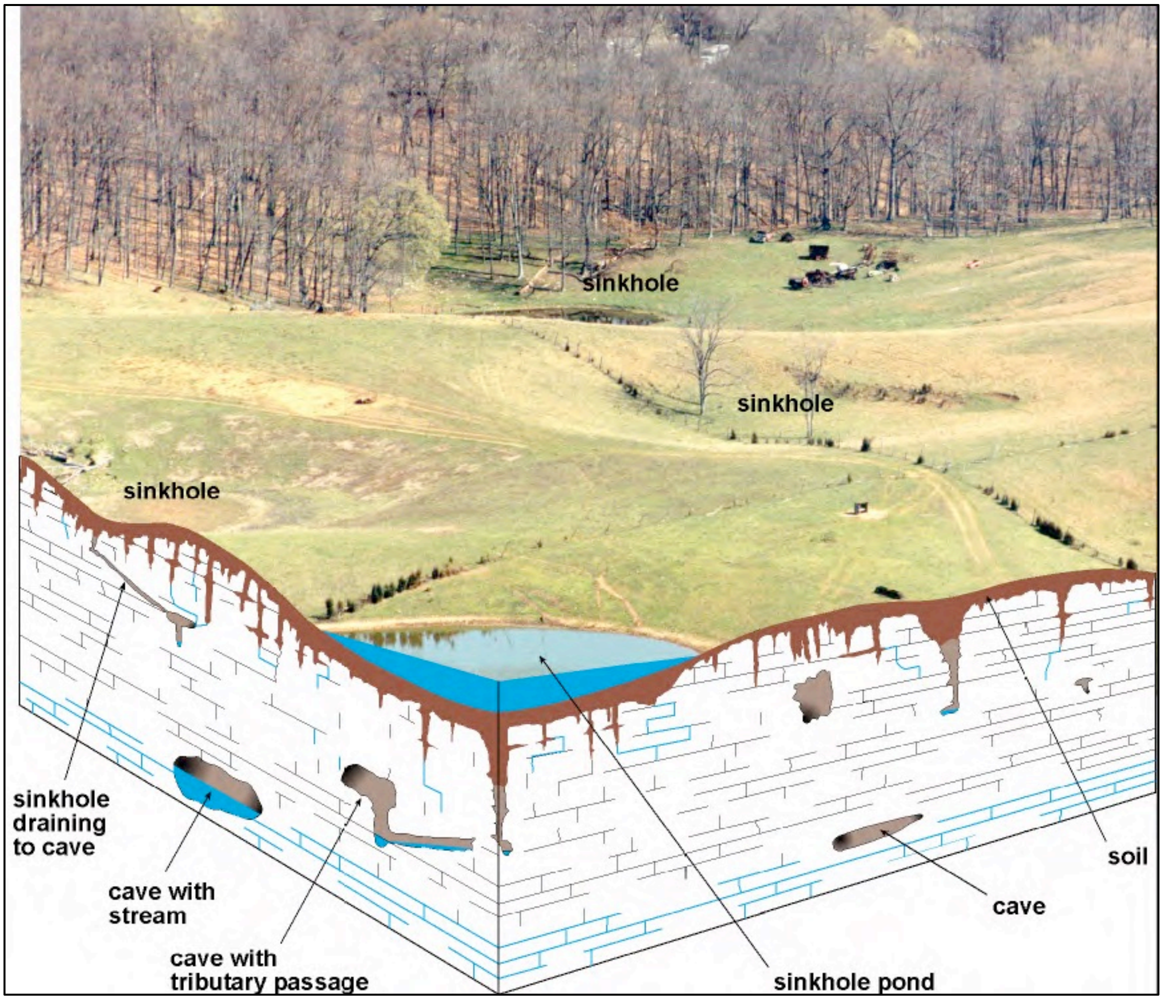
Dissolution sinkholes are formed when bedrock is dissolved and carried away underground. These sinkholes develop gradually, over time, with occasional episodes of soil or cover collapse.

Cover-subsidence sinkholes develop gradually where the covering sediments are permeable and contain sand. In areas where cover material is thicker or sediments contain more clay, cover-subsidence sinkholes are relatively uncommon, are smaller, and may go undetected for long periods.

Cover-collapse sinkholes can develop abruptly over a period of a few hours and cause catastrophic damage. These sinkholes occur where covering sediments contain a significant amount of clay. Over time, surface drainage, erosion, and deposition of a sinkhole turn it into a shallower bowl-shaped depression. Land Subsidence which can be a result of this action is included in a separate narrative at the end of this section.

Geologic Hazards in Karst

Human safety and economic losses are the results of most naturally occurring geologic hazards. There are two common karst-related geologic hazards: cover-collapse sinkholes and sinkhole flooding.



Karst System. *Source: Kentucky Geological Survey*

According to the Kentucky Geologic Survey, *cover-collapse* sinkhole occurs in the soil or other loose material overlying bedrock. As overlying soil is repeatedly wetted and dried, small amounts of soil are dislodged and carried away by the cave conduit draining the sinkhole. The collapse only occurs in the overlying soil, and not in the limestone bedrock.

Cover-collapse sinkholes can vary in size from 1 or 2 feet deep and wide, to tens of feet deep and wide. Soil thickness and cohesiveness determine the size of a cover-collapse sinkhole. Cover-collapse sinkholes in Kentucky are rarely more than 20 feet in diameter due to the thickness of soil, sand or clay, and bedrock fragments that overlay the limestone bedrock. Unlike cover-collapse sinkholes in Florida that swallow entire houses and businesses, that is unlikely to happen in Kentucky where the overlay is less dense. However, cover-collapse sinkholes in Kentucky do severely damage buildings, drain farm ponds, damage roads, and wreck farming equipment.

The most effective way to avoid cover-collapse sinkhole hazards and damage is to avoid buying or building a structure on any sinkhole that has been filled. Before buying property, look for previous damage such as foundation damage and/or door frames and windows that are out of square. Also check all surrounding land for shallow impressions and arch-shaped cracks in the soil.

Sinkhole flooding occurs when there is more precipitation than the conduits and caves can handle. Unlike a normal stream channel, the cave conduit channel has a fixed diameter and cannot expand as flow increases. There are two types of sinkhole flooding. In the first type, the sinkhole conduit may be constricted and unable to carry water away as fast as it flows in. This can occur when the throat of the sinkhole is clogged by trash and junk, soil eroded from fields or construction sites, and sometimes by rock fall within the conduit. Or, at times, the diameter of the conduit is too narrow to handle the volume of water flow. The second type of sinkhole flooding is caused by discharge capacity being limited farther downstream. This can happen when caves are blocked by trash or rock fall, have limited conduit size, or from back flooding from other sinkholes. Sinkholes that may drain normally during moderate rain, may become springs and discharge water from their throats during intense storms.

Sinkhole plain before a rain. Sinkhole plain after a rain.

Source: Kentucky Geological Survey

All structures built in a sinkhole or karst valley are prone to flooding, and little can be done to mitigate future flood damage, except to move the structure. Some sinkholes are so large, that it is difficult to determine that a building site is actually a closed depression. It is always the best practice to consult a topographical map, inspect an area to determine its relative elevation, look for previous signs of water damage, and research historic flooding events.

Probability/Impact

The Lincoln Trail Region is dotted with sinkholes and underlain by karst topography. Extensive mapping of the area has been incorporated into local land use plans and most of these karst/sinkhole sites have not been developed or had structures built on them. The maps included in this section illustrate how prevalent karst topography is in the Lincoln Trail Region. However, there is little quantitative data on historic sinkhole-related events that enables the prediction of the probability of occurrence, or to articulate the extent of impact that the hazard poses for the Lincoln Trail Region. The prevalence of karst topography in the region results in a 100% chance that either a sinkhole collapse or sinkhole flooding event could occur in any given year. Either scenario could result in the destruction or damage of structures and infrastructure and/or the loss of human life. The impact of local sinkhole hazards is exemplified by the Quiggins Sinkhole Flooding event. Since quantitative impact reports for sinkhole hazards do not exist within the Lincoln Trail Region, research must focus on the type of karst topography prevalent in the area. The region is mostly underlain with a system of roofed-over creeks as opposed to actual sinkholes. Consequently, most sinkhole related hazards have been those related to sinkhole flooding and have been aggregated into damages and hazard events associated with flooding. Thus, the Quiggins Sinkhole flooding stands as an identified example of the impact and existence of regional sinkhole hazards.

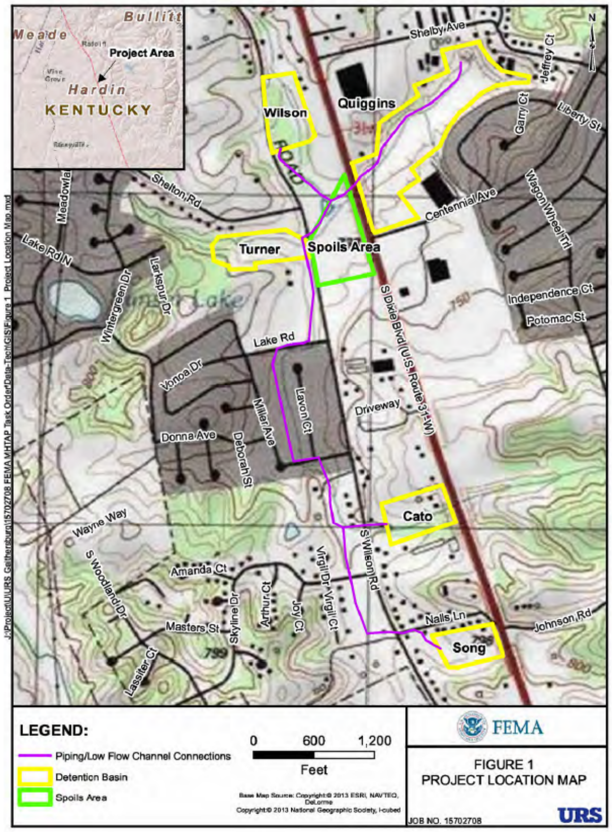
A large area sinkhole is in Radcliff in Hardin County. The significance and impact of the hazard was enough to justify the 2015 FEMA Hazard Mitigation Grant financing of a sinkhole mitigation project that exceeds $5 million. The Quiggins Sinkhole lies within the Happy Valley watershed and is concentrated around 24 acres of land. A primary hydrology study and FEMA environmental analysis used for the project's application relied on impacts to housing and public works within this area in the City of Radcliff. From this single event, hydrology studies determined damages based upon recurrence probability. Work to prevent sinkhole related flooding is currently underway and should improve water management in the area. The Quiggins Sinkhole Flood Mitigation Project will construct four retention basins and expand a fifth to mitigate the effects of widespread flooding. The Quiggins Sinkhole is one of 86 known sinkholes into which the City of Radcliff drains. Using the recurrence intervals cited, only impacts to housing and public works within the 24-acre site, for this one sinkhole were calculated.

Table 3.3.2.8.1 - Quiggins Sinkhole Impact Costs

Recurrence Interval	Housing Damages (In Dollars)	Public Works Damages (In $)	Total Damages (In Dollars)
200	$969,123	$91,697	$1,737,628
100	$623,019	$80,381	$1,296,687
50	$420,027	$69,455	$1,002,128
25	$264,344	$59,310	$761,419
10	$171,617	$46,824	$564,045
5	$56,176	$37,849	$373,388
2	$13,210	$27,704	$245,397
1	$358,408*	$19,900	$525,190
* Refers to "Less Than One-Year Damages"			

When adjusted for inflation, the total benefits of mitigating the impacts of one sinkhole, using assumptions of one representative hazard event that occurred in Radcliff in 2008, was calculated at $5,679,173.

Ongoing work on Quiggins Project, *Source: Greg Thompson, News-Enterprise, March 2016.*



Quiggins Sinkhole Flood Mitigation Project Location Map. *Source: FEMA Environmental Assessment Feb. 2015.*

In addition to sinkhole flooding effects, the prevalence of karst terrain within the Lincoln Trail Region must be considered when analyzing and thinking about the number and value of significant historic sites located in the area that may be situated on or near sinkholes. Rich in Lincoln history, the Lincoln Trail Region is home to many valuable historic sites such as the Joseph Holt House located on KY 144 in Breckinridge County and Lincoln's grandfather's homestead, the Lincoln Homestead, located outside of Springfield in Washington County. The Abraham Lincoln Birthplace, part of the National Parks system, is located outside of Hodgenville in LaRue County, on a site that was called the Sinking Springs Farm, an area underlain by twelve (12) sinkholes. All these sites are valuable historic sites, priceless and irreplaceable. The 2003 Executive Order 13287: Preserve America states: "The Federal government shall recognize and manage the historic properties in its ownership as assets that can support department and agency missions while contributing to the vitality and economic well-being of the Nation's communities." The federal government recognizes not only the intrinsic value of historic sites, but also the economic benefits associated with them that positively impact local property values, jobs, tourism, and revenue. Consequently, the impact of sinkhole collapse at the Birthplace site would have a significant financial impact far exceeding the hazard event itself.

Extent

To exemplify impact, the Radcliff Quiggins Sinkhole Flooding event was used and shall be used again to address the extent of a sinkhole/karst hazard. Based on one 2008 event, multiple hydrology studies and an environmental assessment conducted by FEMA, determined that it was feasible that over $5.5 million in damages could potentially result from the Quiggins Sinkhole in Radcliff. It was determined that the Quiggins Sinkhole was capable of discharging floodwaters at 11.9 cubic feet per second (cfs), analogous to the flow capacity of a 12-inch pipe. This could easily result in major flooding with as little as one inch of rainfall over a six-hour period according to FEMA's 2/12/2015 "Environmental Assessment: Quiggins Sinkhole Flood Mitigation Project. City of Radcliff, Hardin County, Kentucky, DR-KY-1818-0012."

3.3.2.8.1 <u>Land Subsidence</u>

NOTE: This section previously stood alone as a specific Hazard in the Lincoln Trail Hazard Mitigation Plans from 2005 & 2010. It has been moved to this section as of the 2015 Plan.

I. Background

According to the U.S. Geological Survey (USGS), land subsidence is defined as the gradual settling or sudden sinking of the Earth's surface due to subsurface movement of earth materials.

USGS goes on to say that while land subsidence is a global problem, it impacts the United States substantially. More than 17,000 square miles in 45 states, have been affected by subsidence. The principal causes of land subsidence are aquifer-system compaction, drainage of organic soils, underground mining, hydro-compaction, natural compaction, sinkholes, and thawing permafrost. More than 80% of land subsidence in the United States is a consequence of human impact on subsurface water, and is an often, overlooked environmental consequence of our land water-use practices. Increased development of our land and water resources threatens to exacerbate existing land-subsidence problems and initiate new ones.

Cause of Subsidence

Several causes of land subsidence have been identified and include dissolution of limestone, mining, extraction of natural gas, groundwater-related subsidence, faulting induced, isostatic subsidence, drainage of organic soils, and seasonal effects. This section will only describe those that have a potential of threat in the Lincoln Trail Region.

Dissolution of limestone occurs in karst terrains where dissolution of limestone by fluid flow in the subsurface causes the creation of voids or caves. When the roof of a void becomes too weak, it can collapse and overlying rock and earth fill fall into the void and causes subsidence on the surface. This type of subsidence can result in sinkholes that can be hundreds of meters deep.

Seasonal effects impact land subsidence. Many soils contain significant proportions of clay that are affected by changes in soil moisture due to their very small particle size. Seasonal drying of soils results in a reduction of soil volume and a lowering of the soil surface. If building foundations are above the level to which the seasonal drying reaches, they will move, and this can result in damage to the building in the form of tapering cracks. Trees and other vegetation can have a significant effect on local drying of soils. Cumulative drying over several years occurs as the tree grows and this can lead to the opposite of subsidence, known as heave or swelling of the soil, when the tree declines or is felled. As the cumulative moisture deficit is reversed, over a period that can last as many as 25 years, the surface level around the tree will rise and expand laterally. This can be more damaging to buildings unless the foundations have been strengthened or designed to cope with the effect.

II. Analysis

To analyze land subsidence as a hazard in the Lincoln Trail Region, much research was done. Sources included FEMA, the Kentucky Geological Survey, the United States Geological Survey and County Emergency Management Agencies.

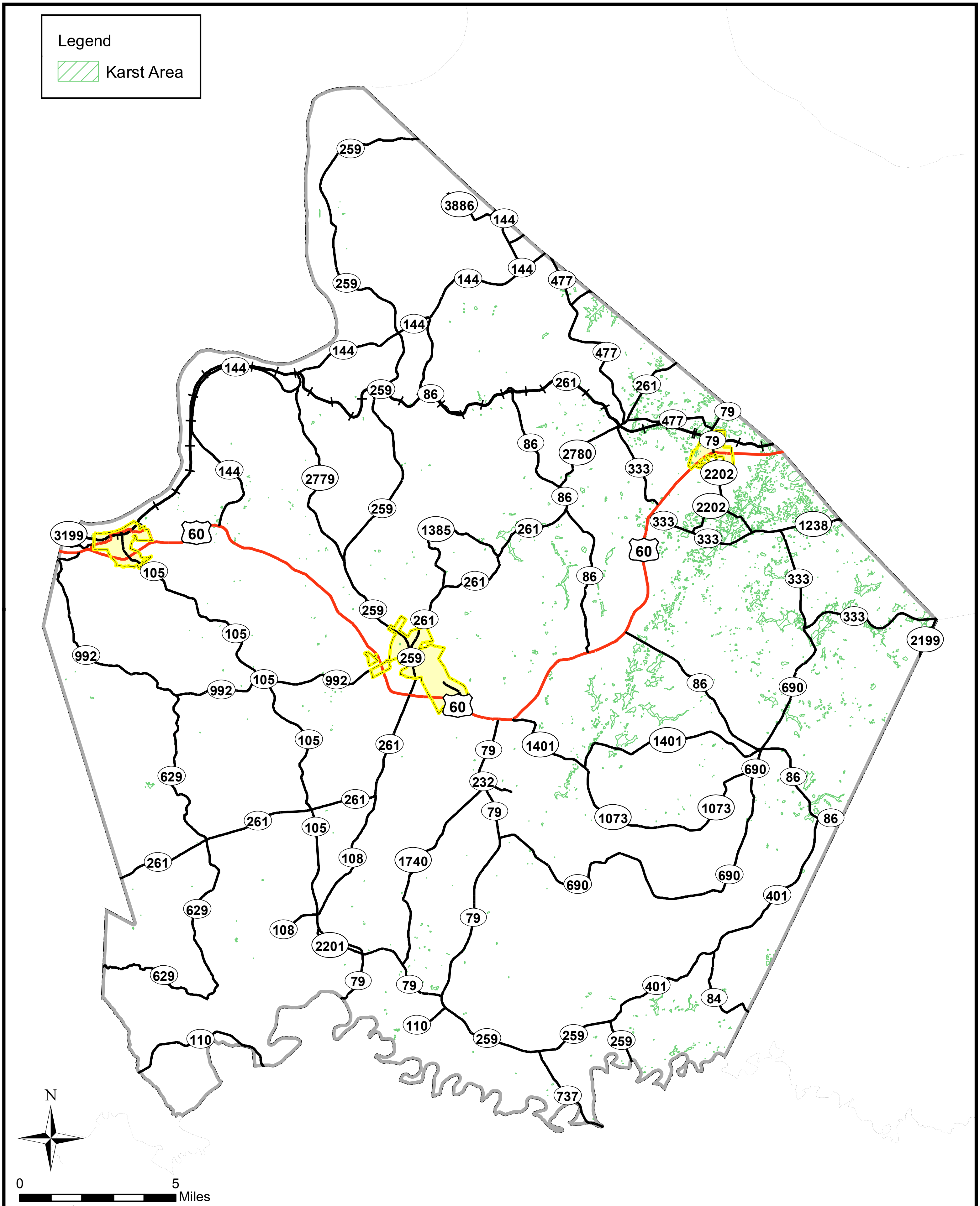
Lincoln Trail Region Subsidence

Subsidence is common in the Lincoln Trail Region, mostly as the result of erosion in areas along creek banks and in the karst topography. Quarry activity is common in the region, but the limestone rock extracted leaves highwalls that are fairly stable. Use of preventative agricultural practices and the proper use of land use management when siting construction projects will alleviate most of the effects of land subsidence in the Lincoln Trail region.

On the Ohio River in Meade County – Feb. 25, 2010,
Source: LTADD Archive.

Image of a calf being rescued from a sinkhole in Meade County in 2019. *Source: The News-Enterprise*.

Sinkhole that appeared in a shopping center parking lot in Elizabethtown in 2018. *Source: The News-Enterprise.*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5
Miles
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60
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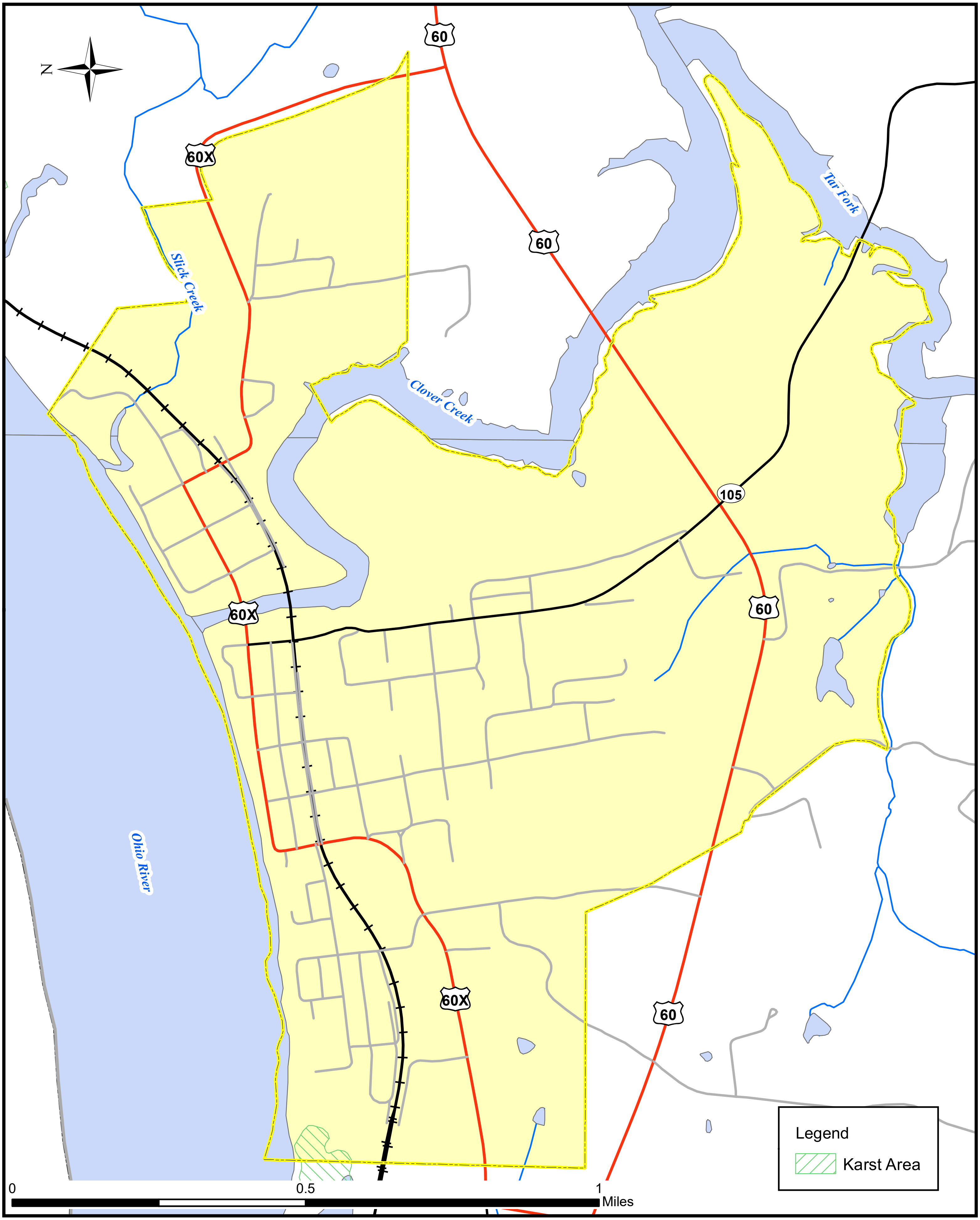
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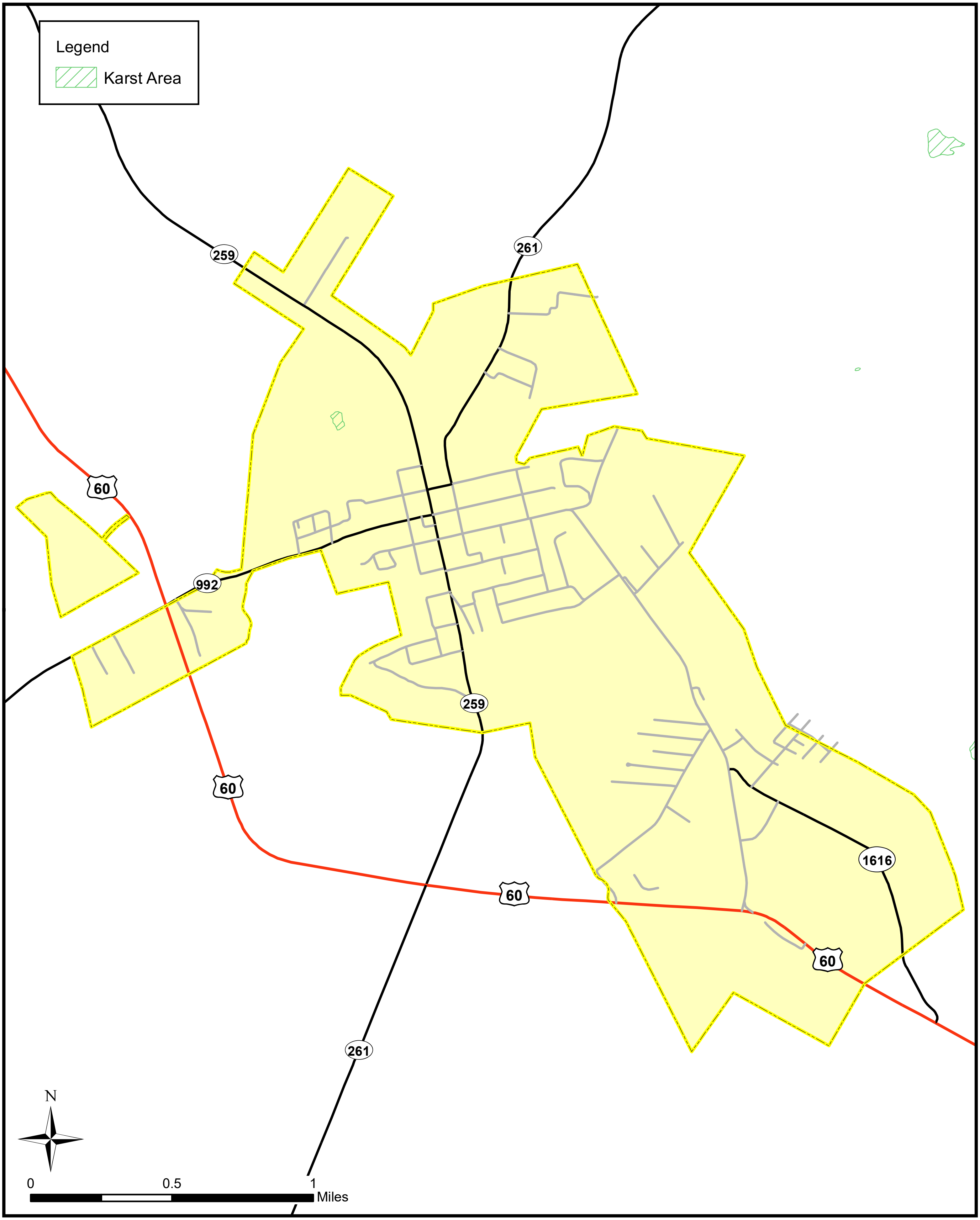
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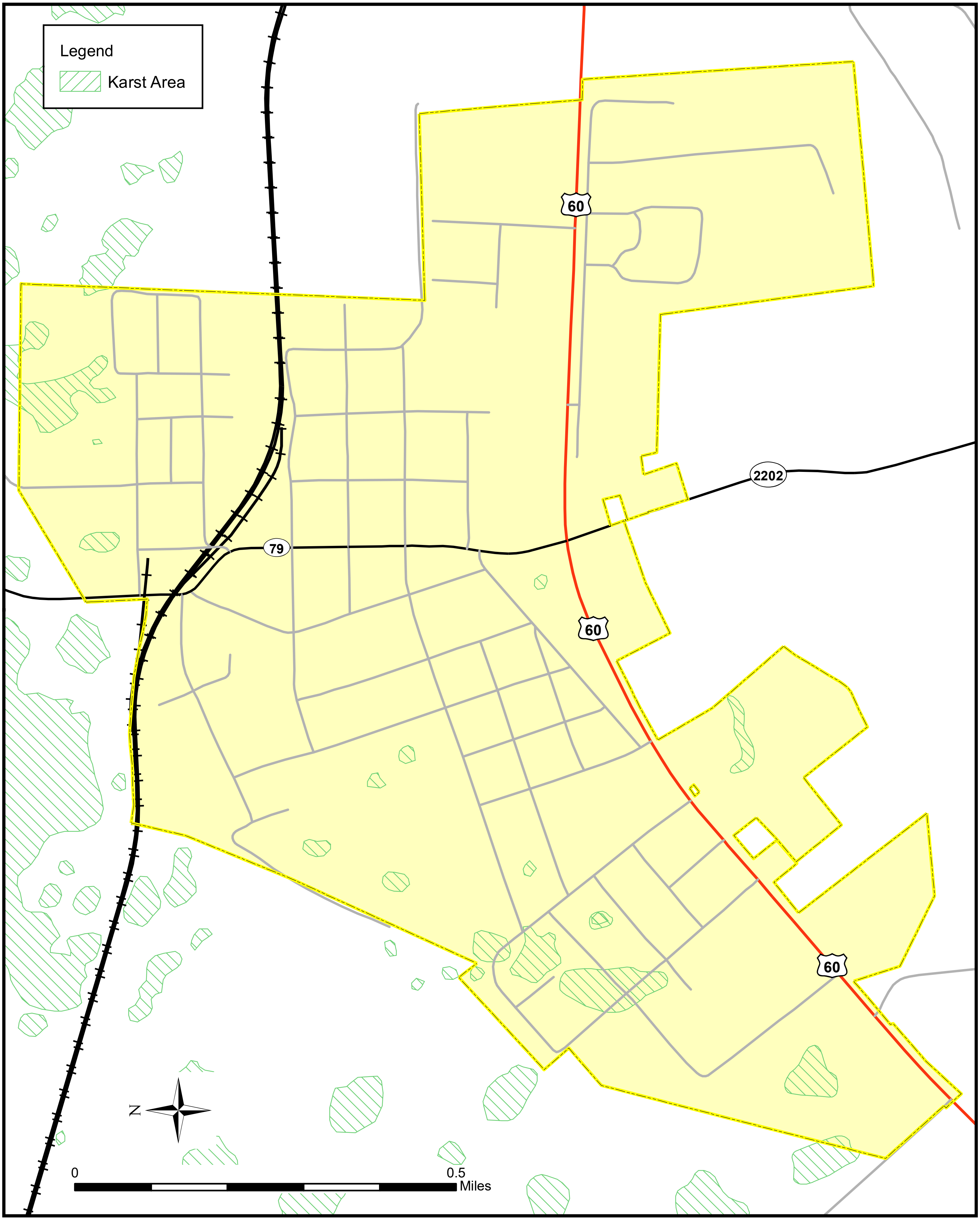
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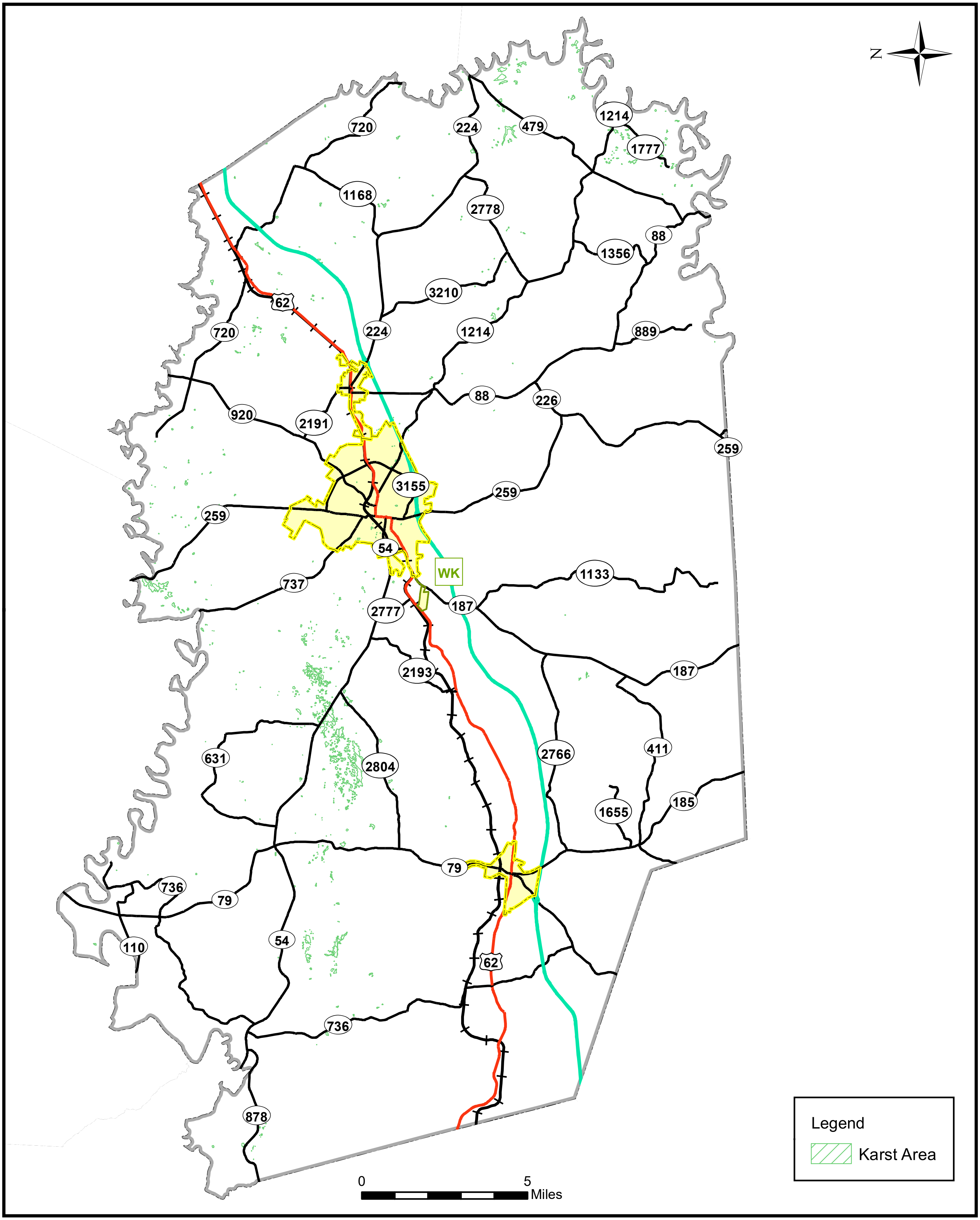
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259
3155
259
259
54
WK
1133
737
187
2777
2193
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2804
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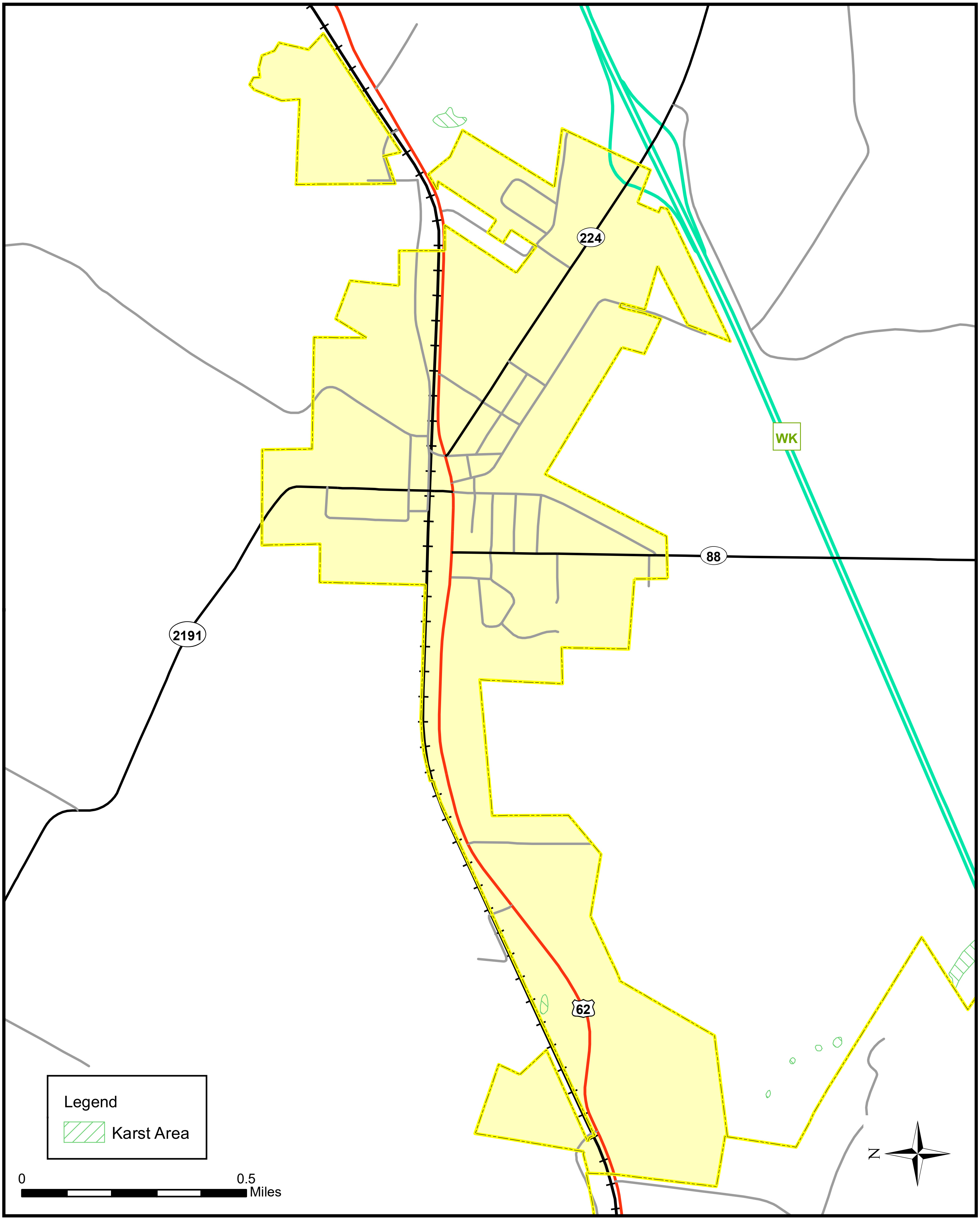
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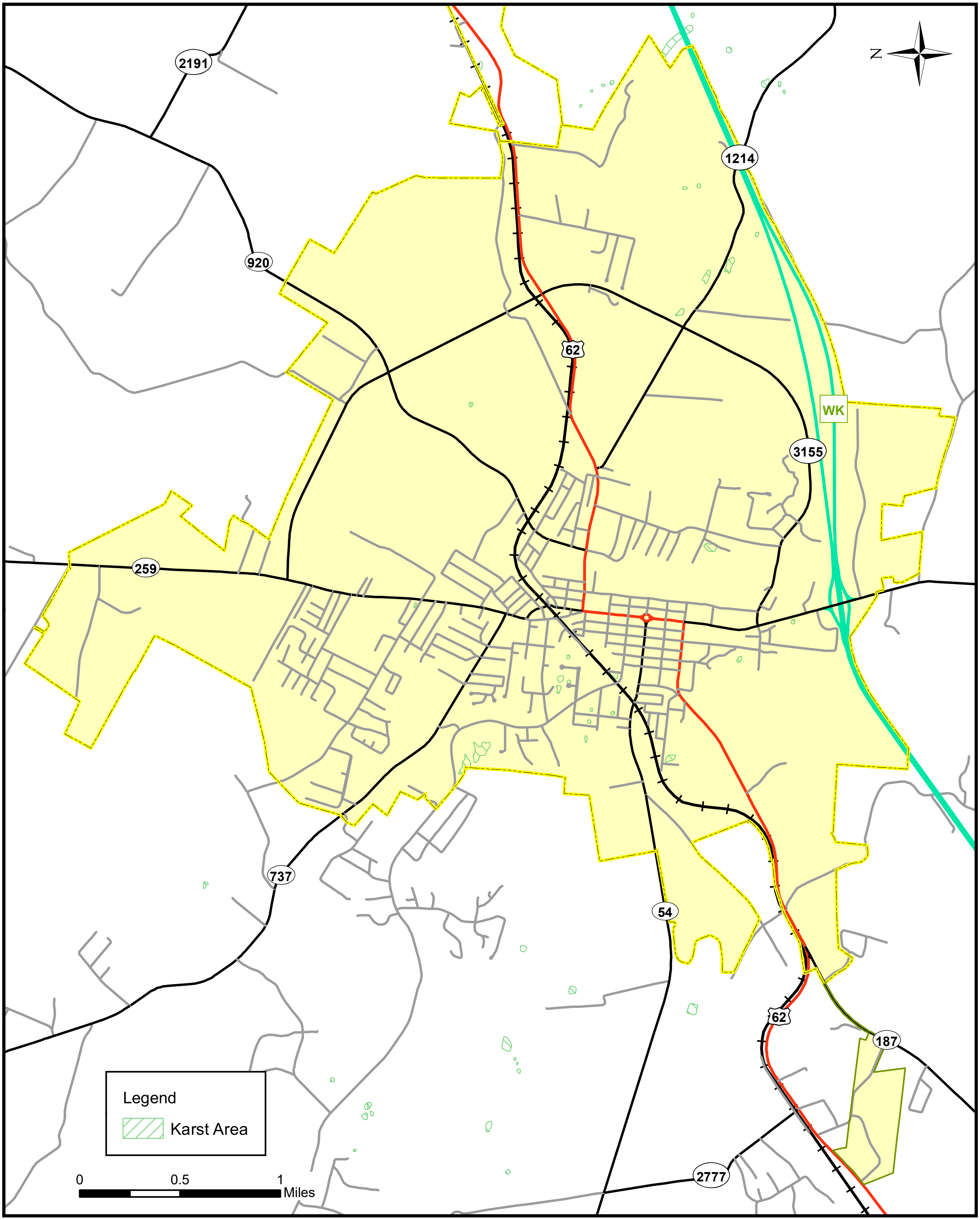
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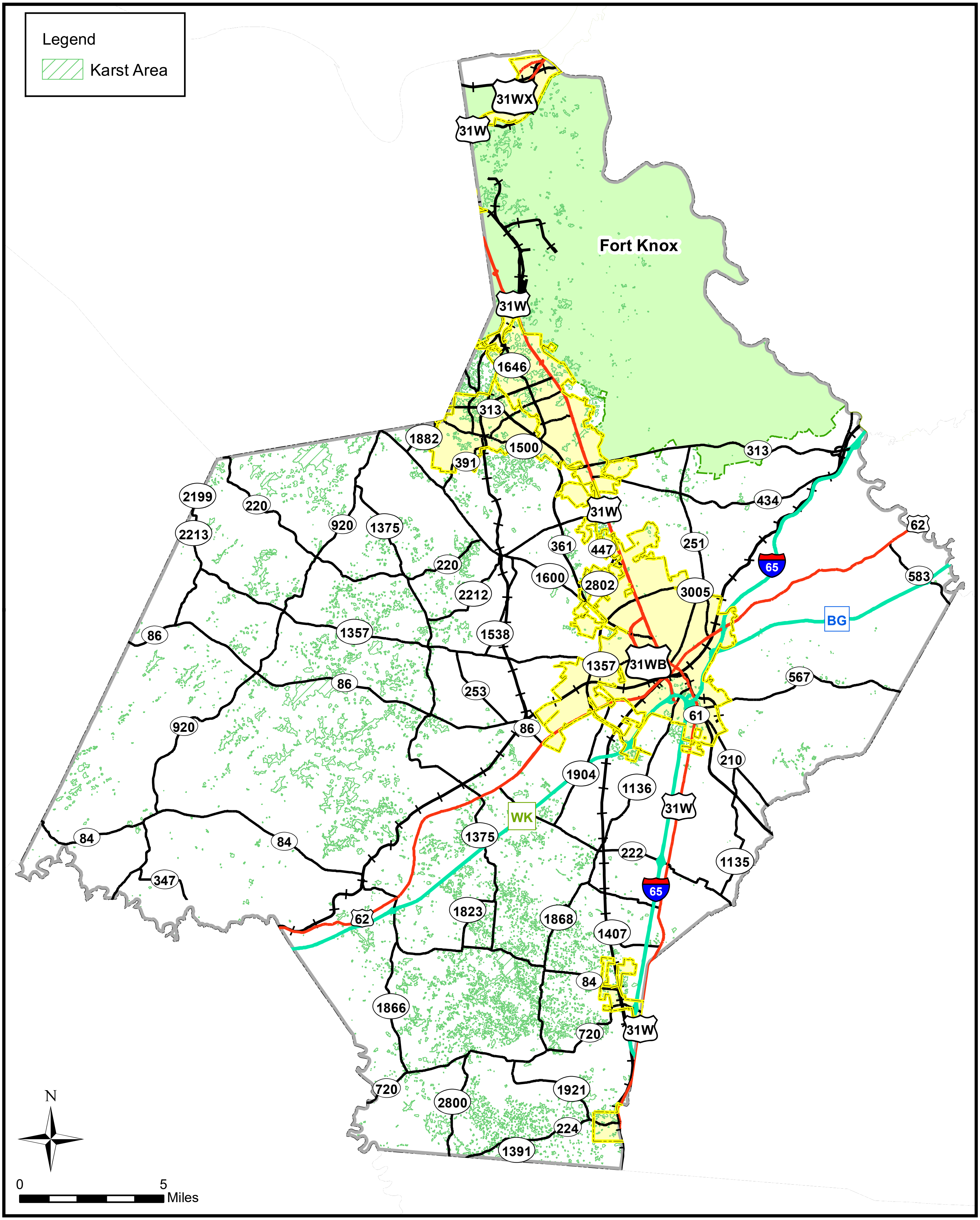
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447
251
62
65
583
1600
2802
3005
2212
BG
86
1357
1538
31WB
567
253
61
210
1904
1136
WK
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2800
1921
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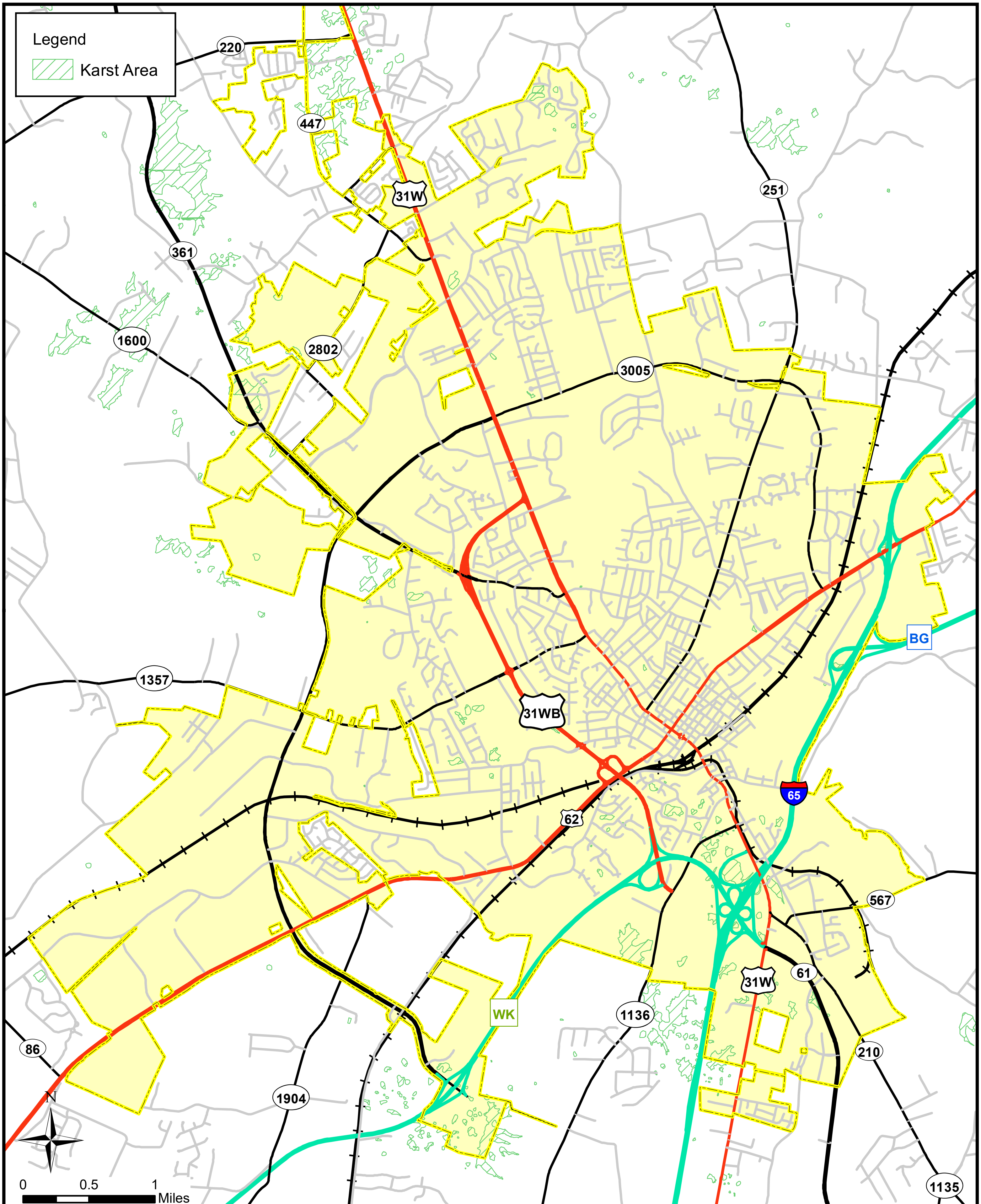
5
Miles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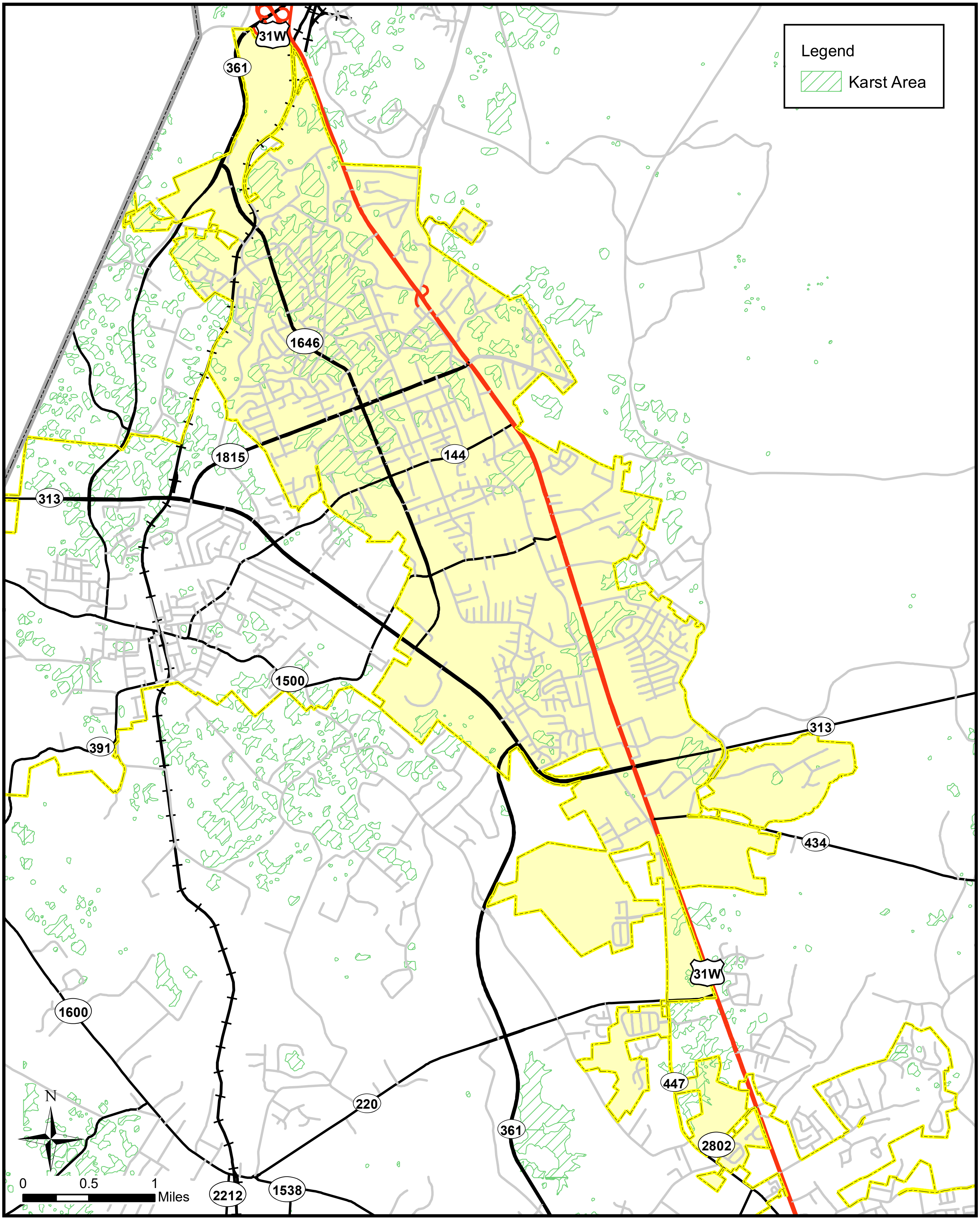
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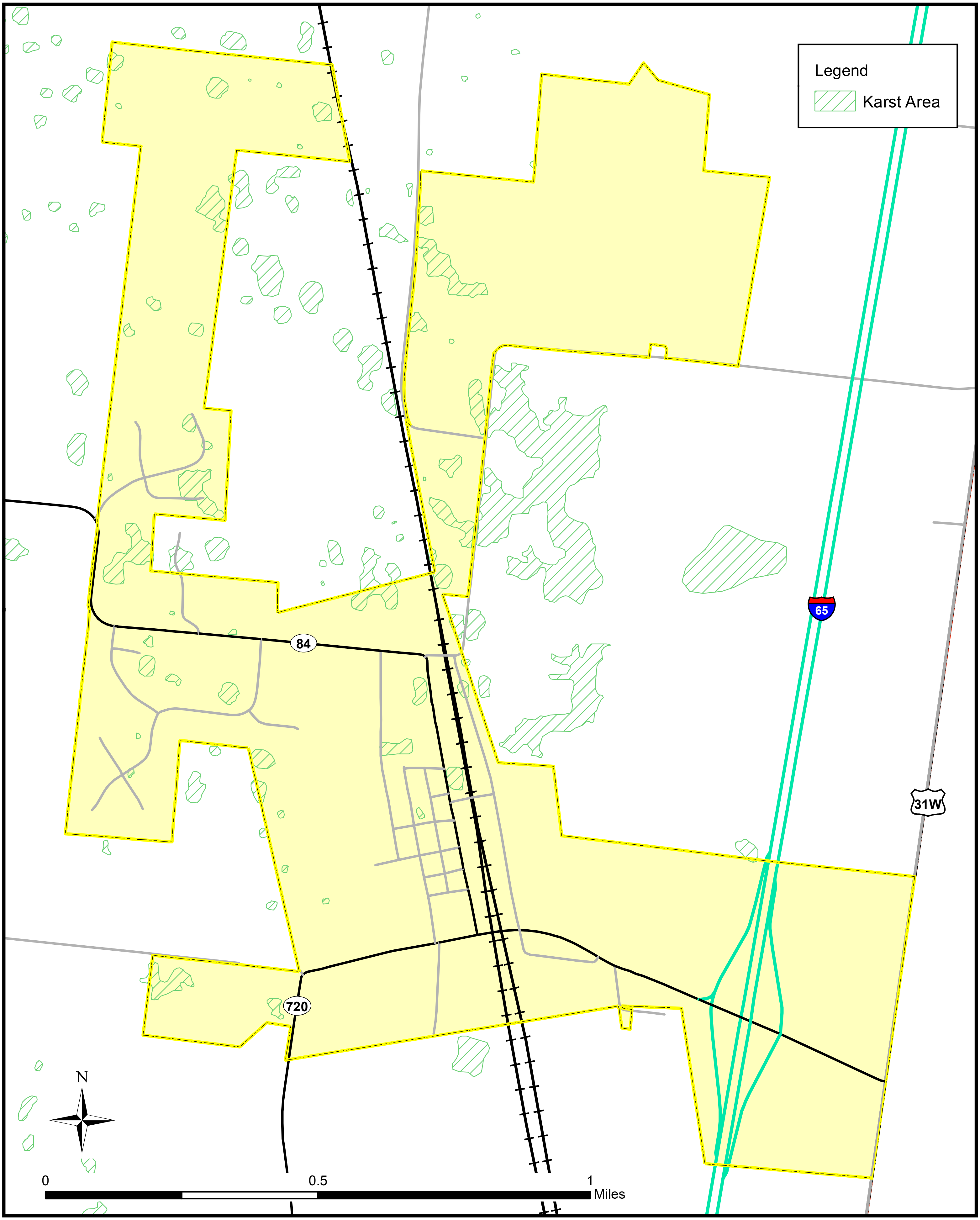
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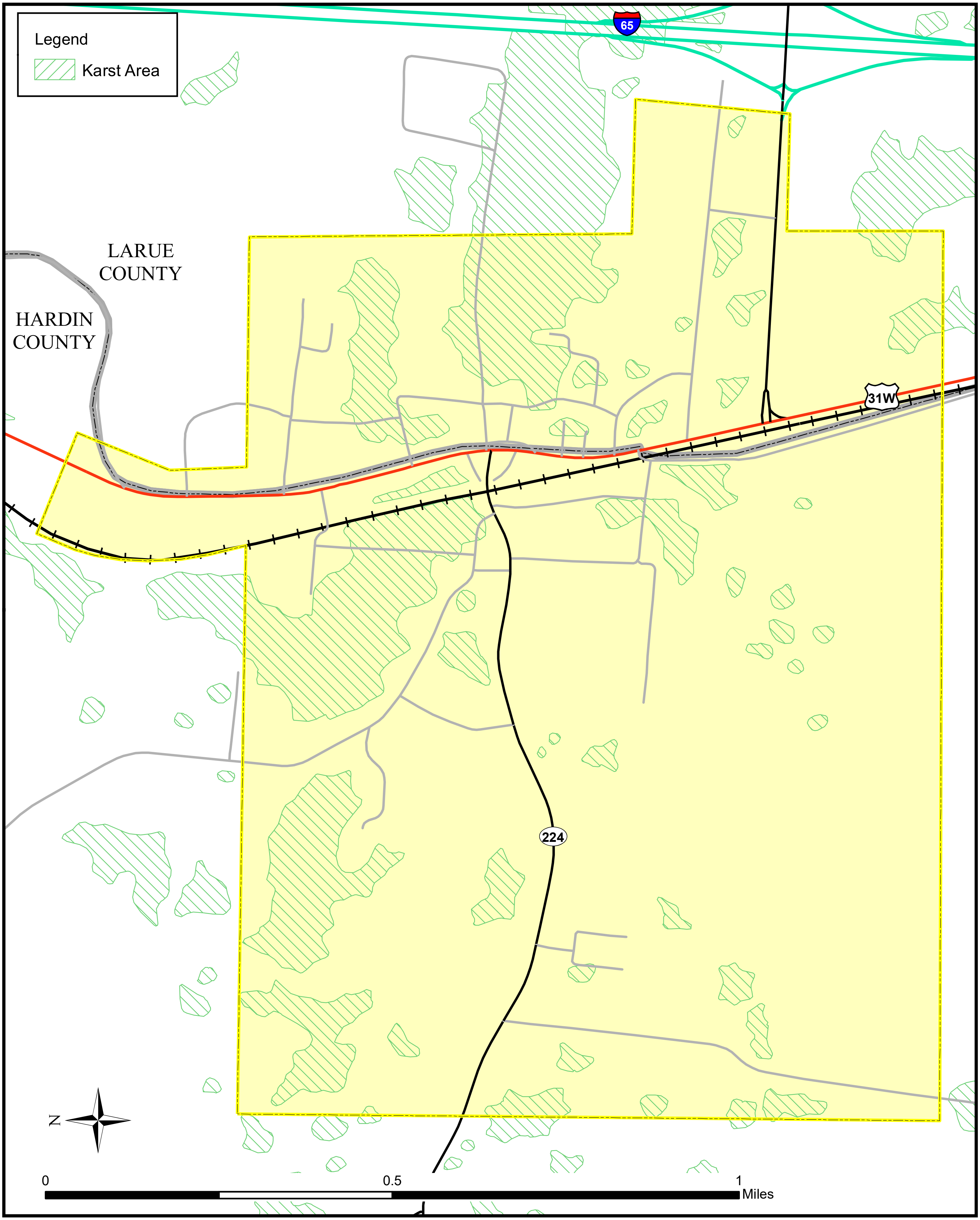
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HARDIN
COUNTY
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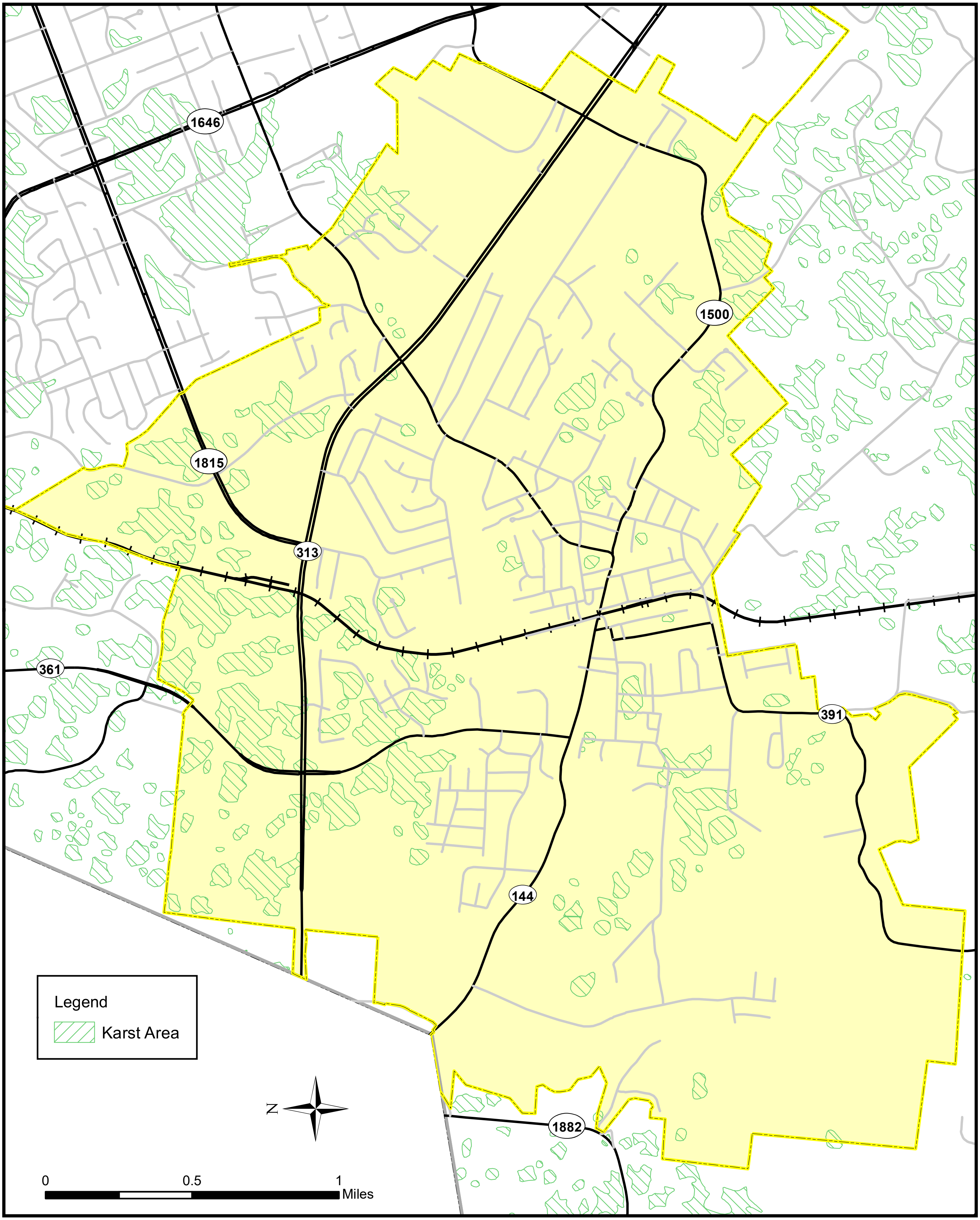
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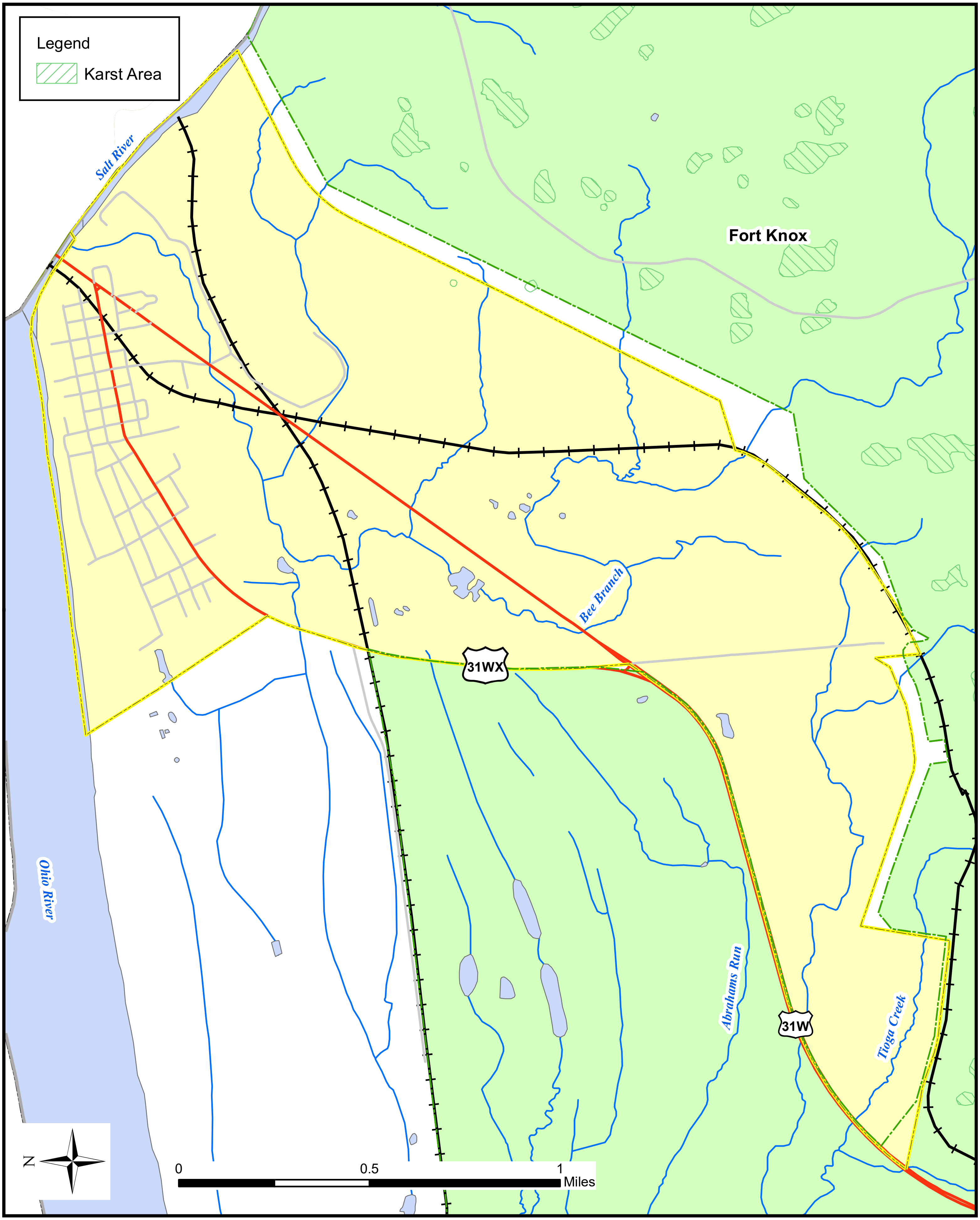
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Fort Knox
Ohio River
Bee Branch
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31W
Abrahams Run
Tioga Creek
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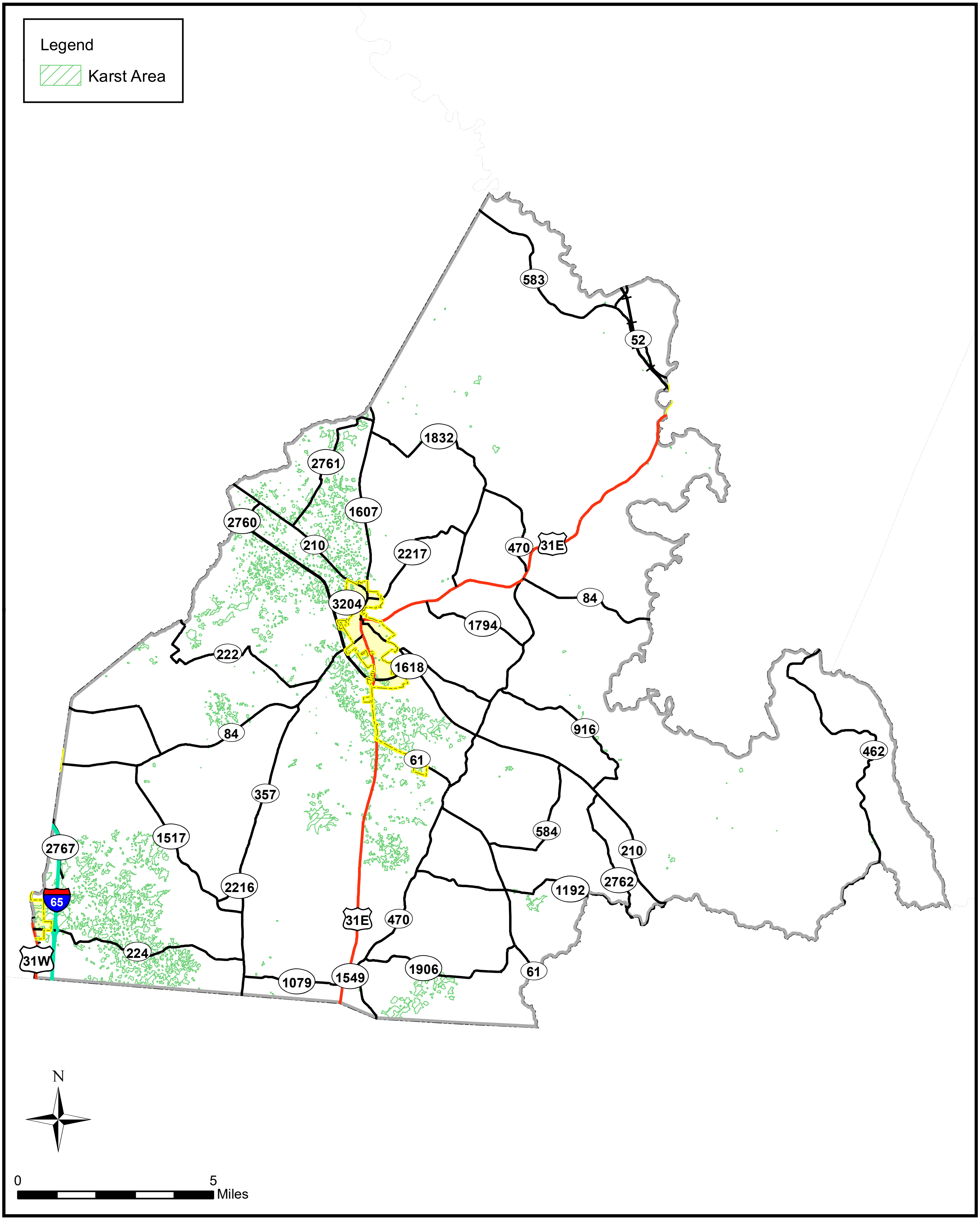
1
Miles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84
916
462
61
357
584
1517
2767
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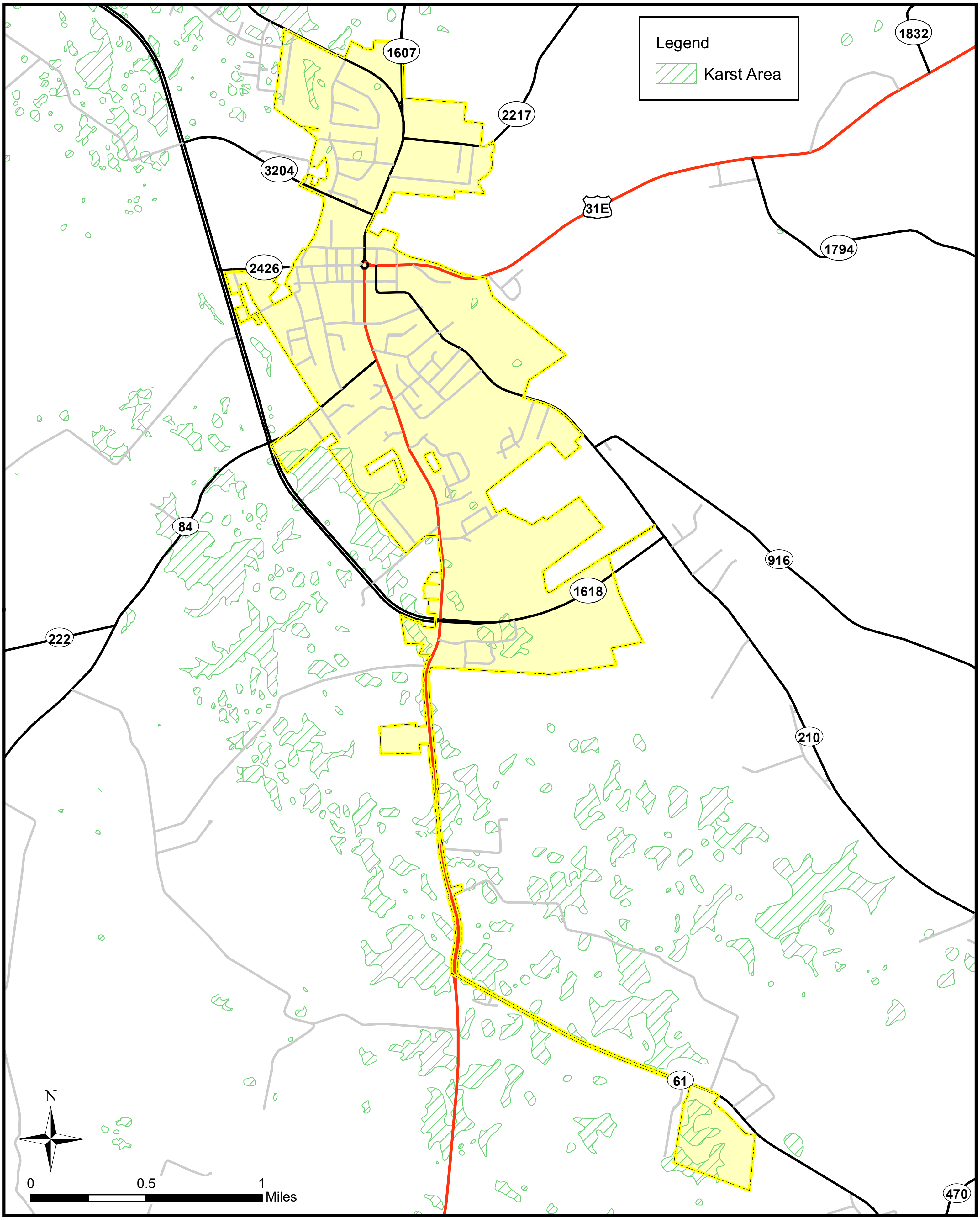
5
Miles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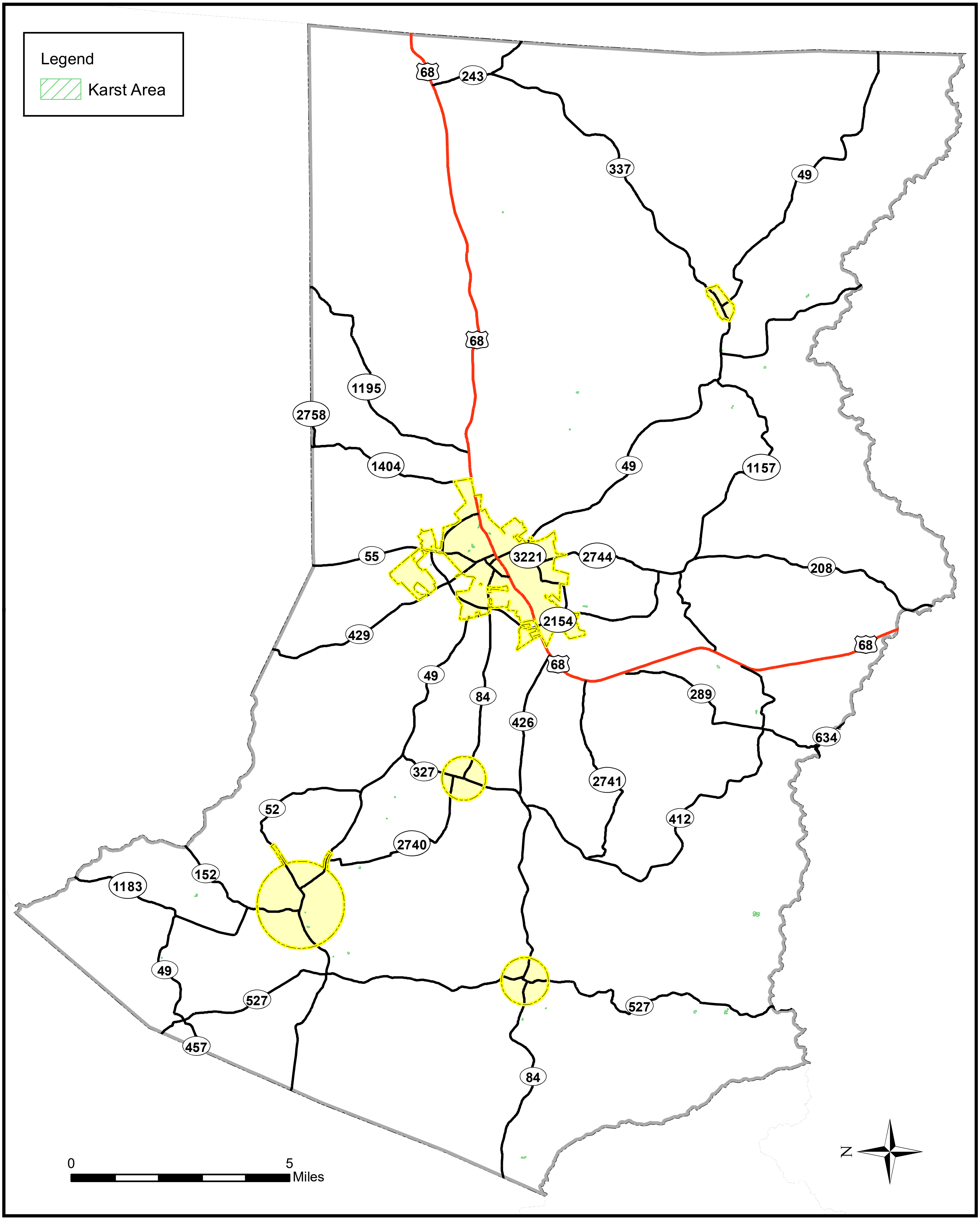
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68
68
49
84
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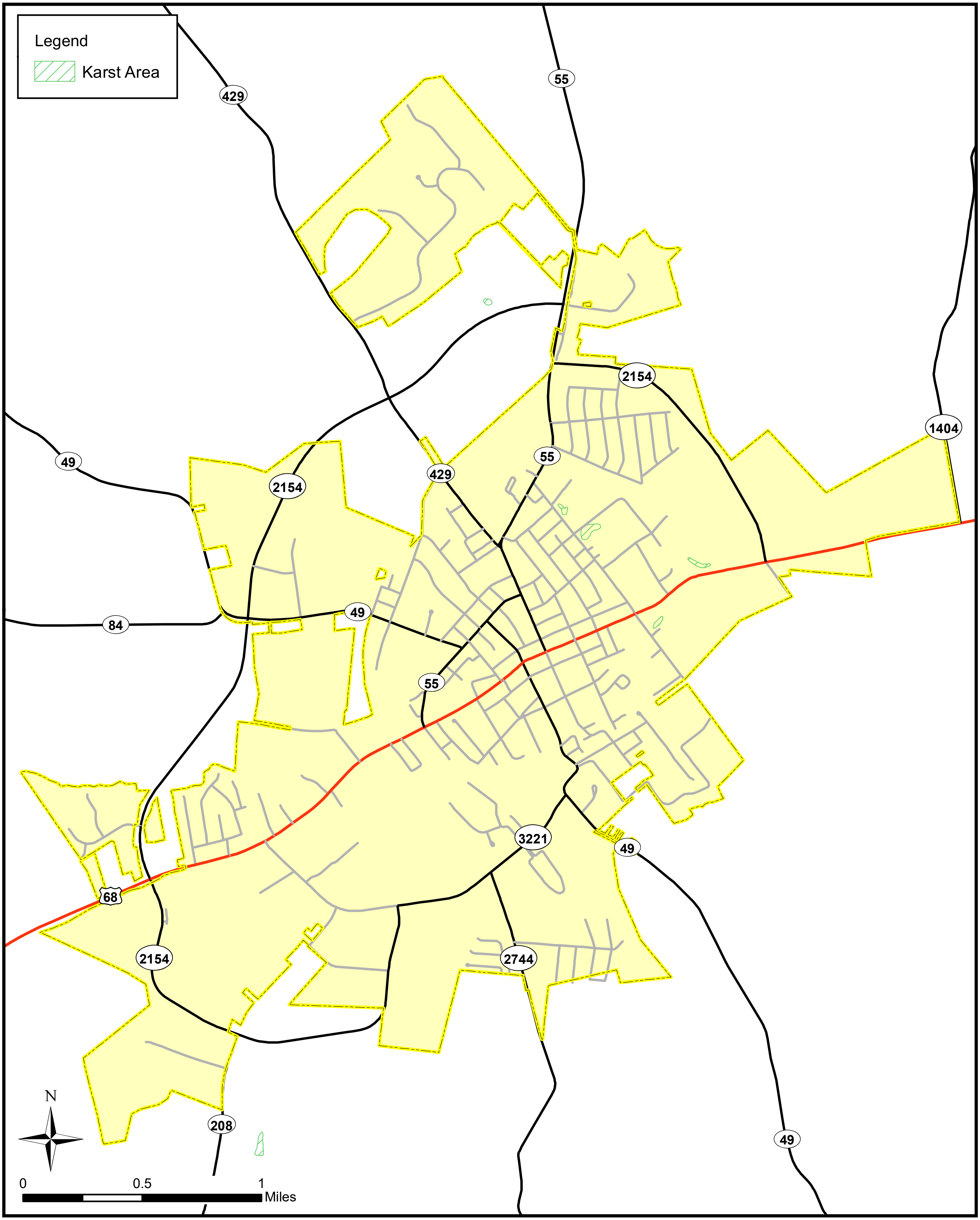
152
1183
49
527
527
457
84
0
5
Miles
N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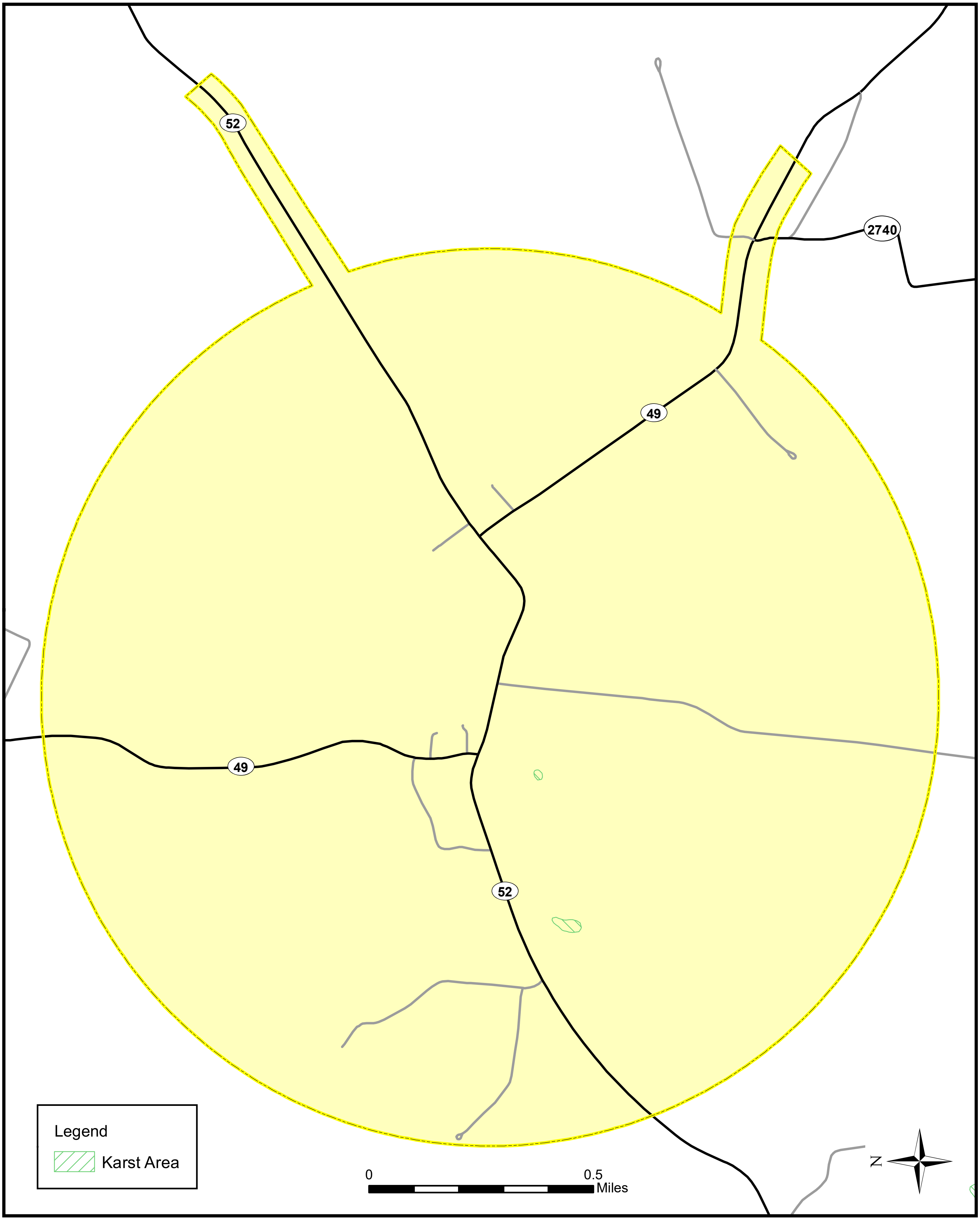
1
Miles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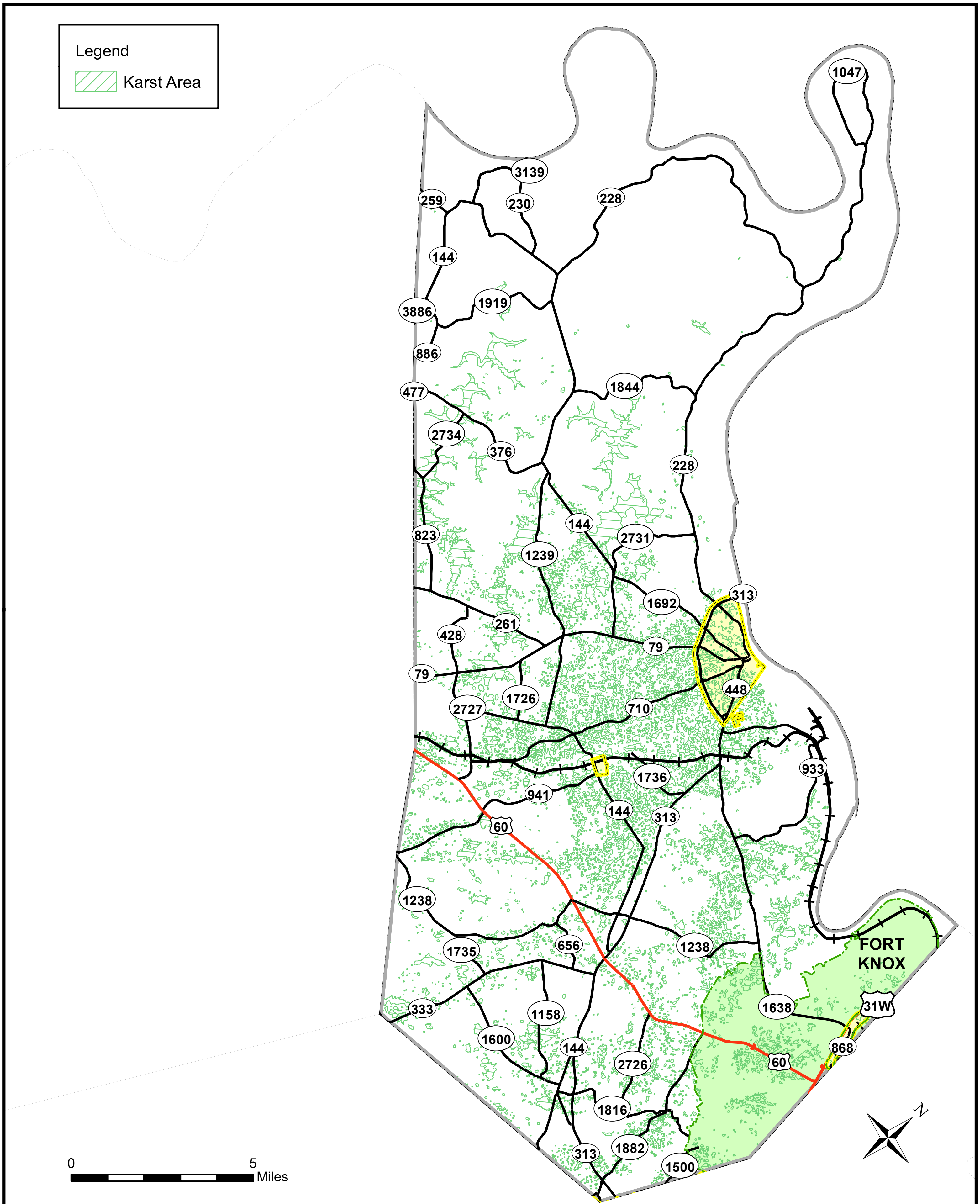
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656
1238
FORT
KNOX
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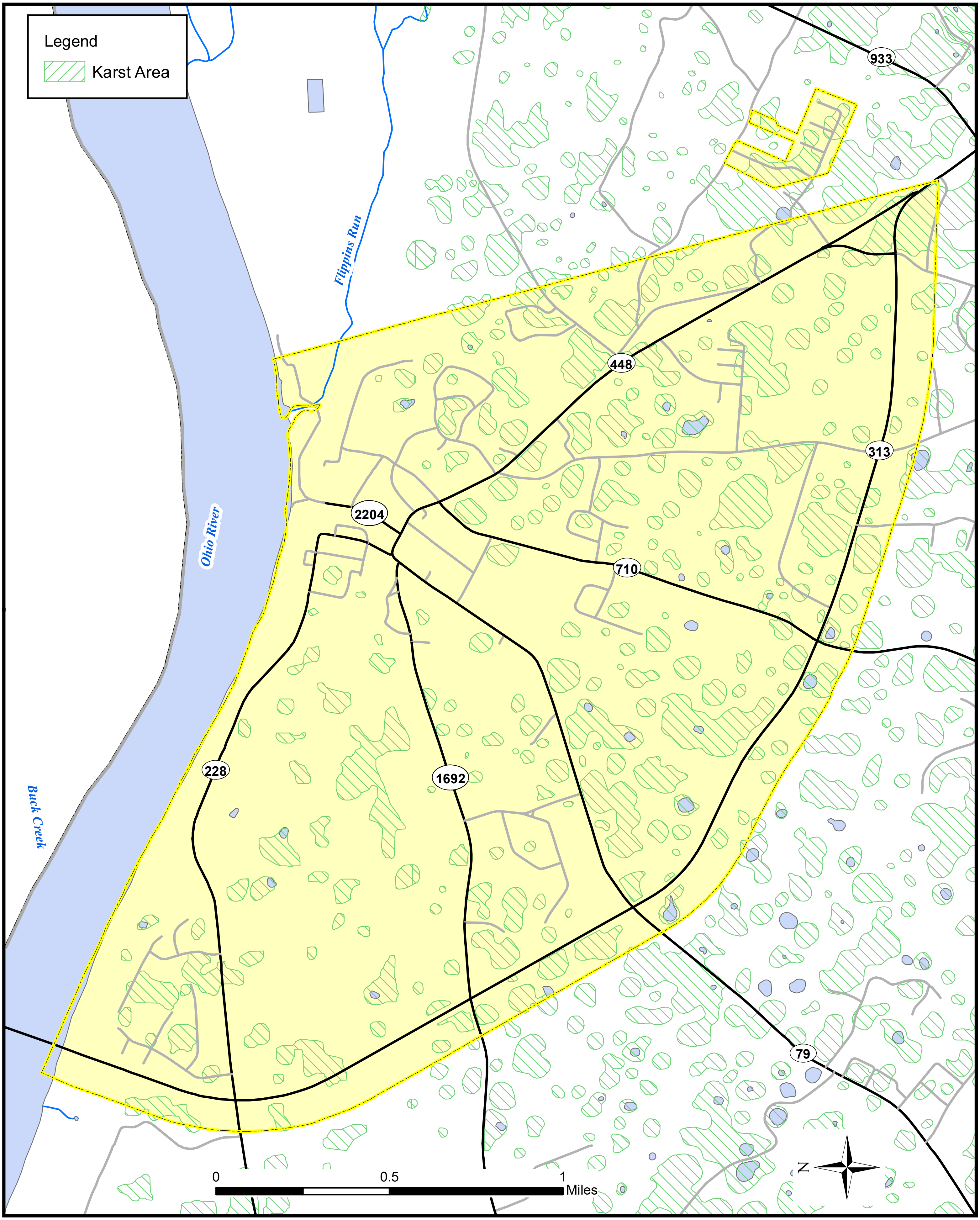
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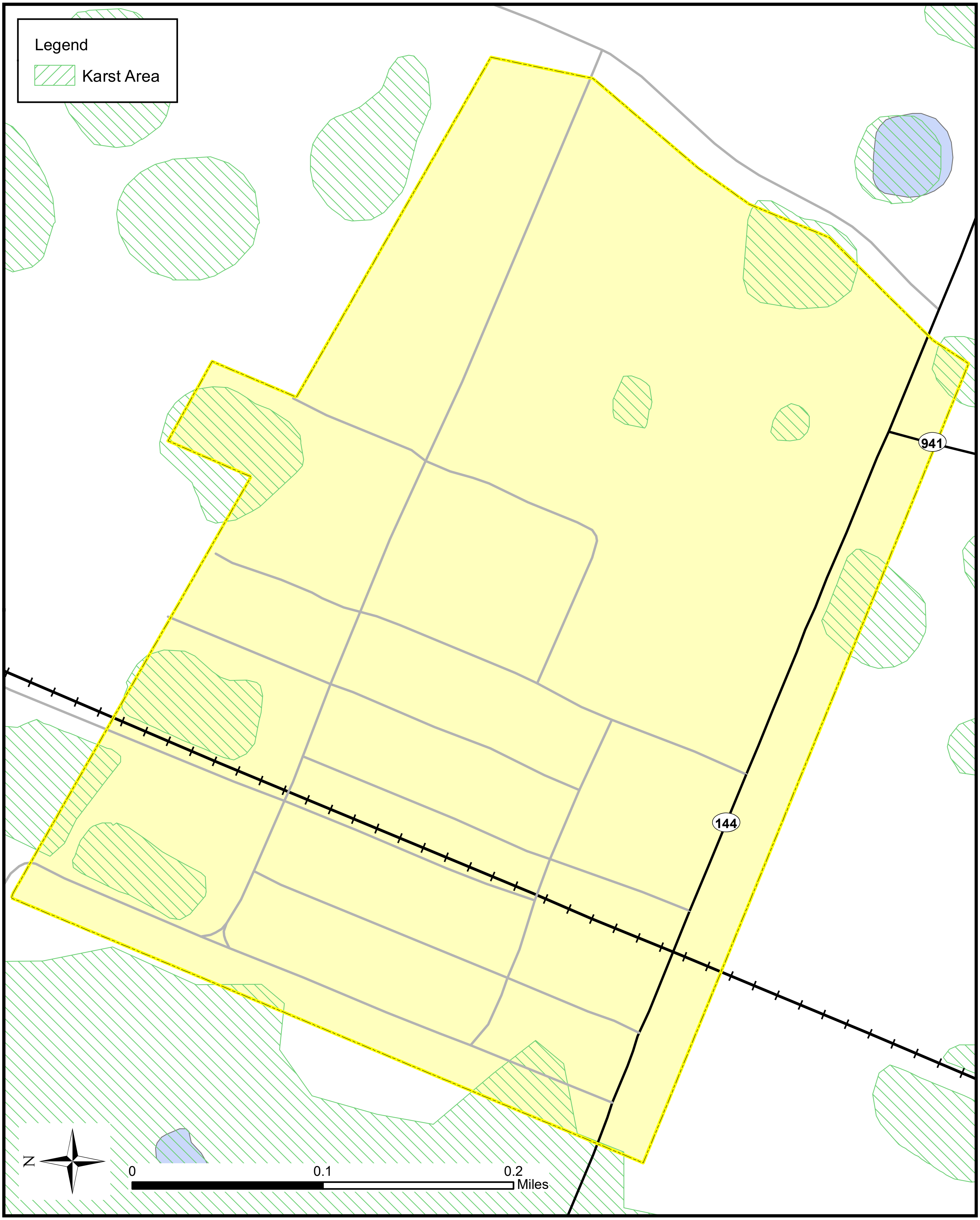
Miles
N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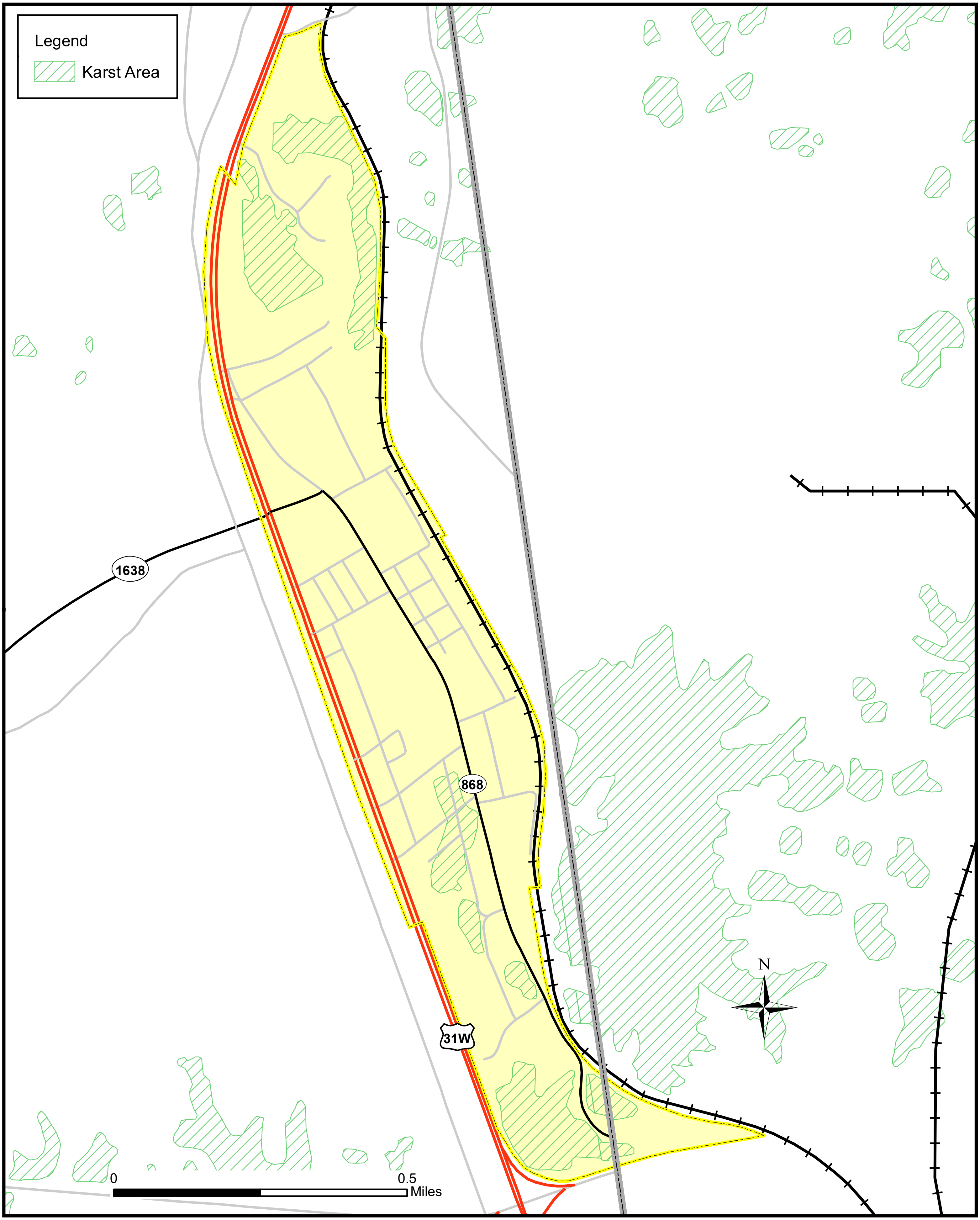
0.1
0.2
Miles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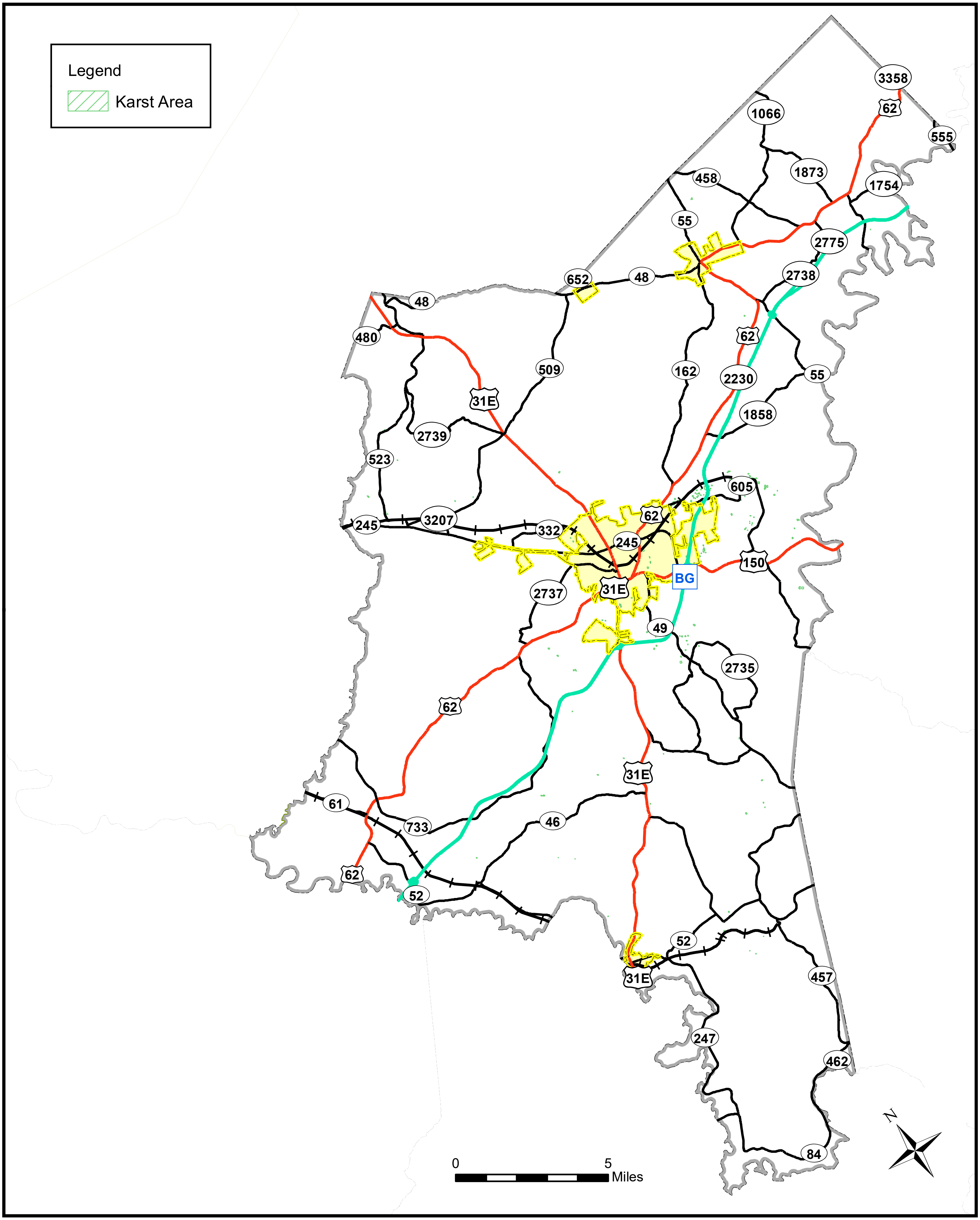
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162
2230
55
31E
1858
2739
523
605
62
245
3207
332
245
150
BG
2737
31E
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Miles
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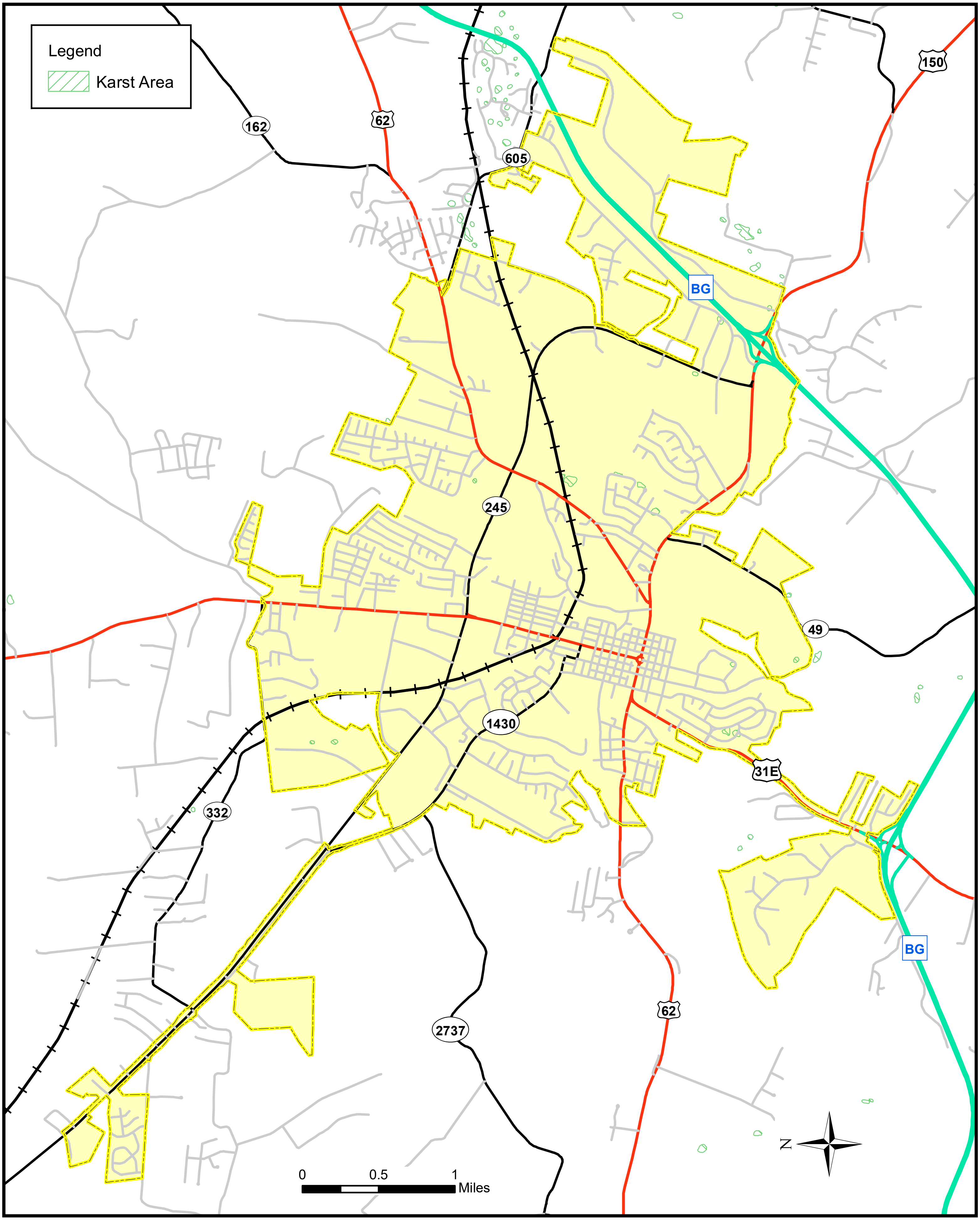
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Miles
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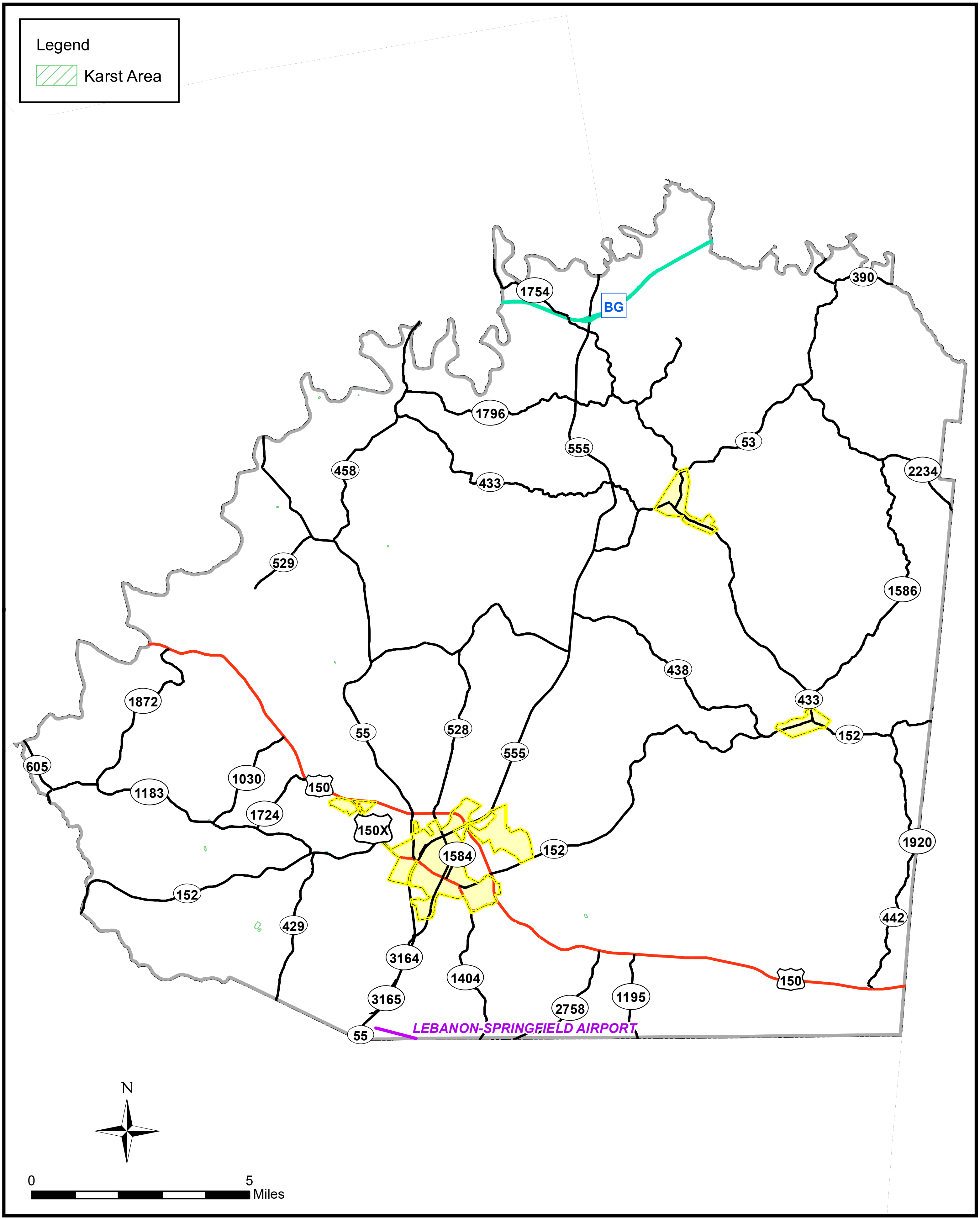
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528
555
152
605
1030
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150X
1584
152
1920
152
429
442
3164
1404
3165
1195
2758
150
55
LEBANON-SPRINGFIELD AIRPORT
N
0
5
Miles

3.3.2.9 Drought

I. Background

The National Oceanic and Atmospheric Administration (NOAA) defines drought as a deficiency in precipitation over an extended period. It is a normal, recurrent feature of climate that occurs in virtually all climate zones. There are cases when drought develops relatively quickly and lasts a very short period, exacerbated by extreme heat and/or wind, and there are other cases when drought spans multiple years, or even decades.

The United States is vulnerable to the social, economic, and environmental impacts of drought. Historical weather records of United States indicate that there have been three or four major droughts over the last 100 years. Two of these disasters, the 1930's Dust Bowl drought and the 1950's drought, each lasted 5 to 7 years and covered large areas of the U.S.

According to the National Climatic Data Center (NCDC), during the 31 years prior to 2011, the United States has experienced 114 weather/climate disasters where overall damages/costs reached or exceeded $1 billion. The standardized losses for the entire 114 events exceeded $800 billion. During that period, there were 16 drought events that totaled $195 billion in losses: an average of slightly over $12 billion per each drought event.

Drought is a normal, recurring global occurrence in most parts of the world. Drought is among the earliest documented climatic events and tied to several biblical stories. Migrations of Hunter-gatherer populations in 9,500 BC Chile have been linked to drought, as has the exodus of early humans out of Africa and into the rest of the world about 135,000 years ago.

Measuring Drought

The Palmer Drought Index, sometimes called the Palmer Drought Severity Index (PDSI), is used to measure drought, and is based on recent precipitation and temperature. Developed by meteorologist Wayne Palmer, the index is based on a supply-and-demand model of soil moisture to measure the departure of the moisture supply. The index is most effective in determining long-term drought and not as good dealing with conditions over a period of weeks. The index uses 0 as normal with drought shown in terms of negative numbers. It also works to describe wet spells, using corresponding positive numbers. The PDSI is calculated based on precipitation and temperature data, as well as the local Available Water Content (AWC) of the soil.

NOAA utilizes the index to publish weekly, Palmer maps for the United States. Global Palmer data sets have been developed based on instrumental records beginning in the 19th century. The chart below illustrates the Palmer Drought Index.

Table 3.3.2.9.1 - Palmer Classifications	
4.0 or more	Extremely wet
3.0 to 3.99	Very wet
2.0 to 2.99	Moderately wet
1.0 to 1.99	Slightly wet
0.5 to 0.99	Incipient wet spell
0.49 to -0.49	Near normal
-0.5 to -0.99	Incipient dry spell
-1.0 to -1.99	Mild drought
-2.0 to -2.99	Moderate drought
-3.0 to -3.99	Severe drought
-4.0 or less	Extreme drought
Source: National Drought Mitigation Center	

An alternative method is the Drought Severity Classification used by the U.S. Drought Monitor service. (http://droughtmonitor.unl.edu/Home.aspx).
It uses a scale of D0-D4 that has a direct relationship to the Palmer method illustrated above.

Table 3.3.2.9.2

Drought Severity Classification

Category	Description	Possible Impacts	Palmer Drought Severity Index (PDSI)
D0	Abnormally Dry	Going into drought: ▪ short-term dryness slowing planting, growth of crops or pastures Coming out of drought: ▪ some lingering water deficits ▪ pastures or crops not fully recovered	-1.0 to -1.9
D1	Moderate Drought	▪ Some damage to crops, pastures ▪ Streams, reservoirs, or wells low, some water shortages developing or imminent ▪ Voluntary water-use restrictions requested	-2.0 to -2.9
D2	Severe Drought	▪ Crop or pasture losses likely ▪ Water shortages common ▪ Water restrictions imposed	-3.0 to -3.9
D3	Extreme Drought	▪ Major crop/pasture losses ▪ Widespread water shortages or restrictions	-4.0 to -4.9
D4	Exceptional Drought	▪ Exceptional and widespread crop/pasture losses ▪ Shortages of water in reservoirs, streams, and wells creating water emergencies	-5.0 or less

Source: http://droughtmonitor.unl.edu/AboutUs/ClassificationScheme.aspx

Types of Droughts

Droughts are typically defined in three main ways:

1. Meteorological droughts occur when there is a prolonged period with less than average precipitation. A meteorological drought usually precedes the other kinds of droughts.
2. Agricultural droughts affect crop production or the ecology of the range. An agricultural drought can occur independently with any change in precipitation levels when soil conditions and erosion, triggered by poorly managed agricultural endeavors, cause a shortfall in the amount of water available to the crops.
3. Hydrological droughts happen when water reserves available in sources such as aquifers, lakes, and reservoirs fall below the statistical average. A hydrological drought tends to show up more slowly because it involves stored water that is used, but not replenished. As with an agricultural drought, this type of drought can be triggered by more than just a loss of rainfall.

Hazards/Consequences of Drought

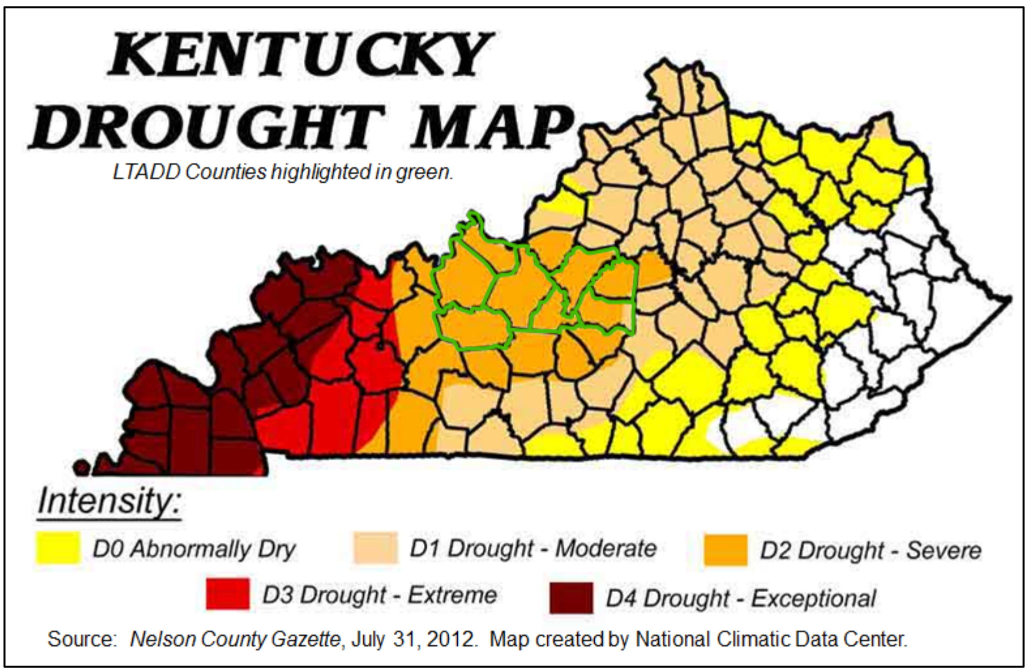
Periods of drought can cause significant environmental, agricultural, health, economic and social consequences. Subsistence farmers and populations dependent on water sources for food are more vulnerable to famine and diminished economic means. Drought can cause a reduction in overall water quality when reduced water flows increase contamination of remaining water sources. Other consequences of drought include:

- Reduced crop growth or yield productions and carrying capacity for livestock
- Dust bowls and landscape erosion
- Dust storms when drought reduces the water content of the soil
- Damage to terrestrial and aquatic life habitats
- Hunger and famine due to reduced food crops
- Malnutrition, dehydration, and related diseases
- Mass migration of humans and wildlife resulting in displaced people and animals
- Reduced electricity because of low water flow through hydroelectric dams
- Water shortages for residential and industrial users
- Snake migration that results in increased snakebites
- Social unrest
- Wildfires are more common during periods of drought and often result in loss of life and widespread property damage
- Exposure and oxidation of acid sulfate soils due to falling surface and groundwater levels
- Navigable waters can become unsafe for navigation because of drought
- Degradation of the environment in the form of erosion and ecological damage may occur as the result of drought

II. Profile

According to NOAA, there have been 52 recorded drought events in Kentucky since 1996. Three of these droughts caused serious damage to agricultural crops. In 1996, drought affected 20 Western Kentucky Counties and crop damage was estimated at $154 million. In 2002, 22 counties were affected by drought with damages estimated at $70 million. The drought of 2012 was a Level 2 drought in 24 Kentucky Counties and a Level 1 drought in an additional 66 Counties. The entire State was at least abnormally dry. Total crop production for State was at 47% of the usual annual yield and crop damage was severe. There was widespread shortage of animal feed as well. There were no deaths attributed to these drought events, however, they did affect agriculture, tourism, wildlife, residential and commercial water use, recreation, wildlife habitat, increased wildfires, electric power generation and water quality. Since the 2012 drought events the state has not experienced significant drought events.

The map below illustrates the widespread effect and severity of the 2012 drought in Kentucky.



North Rolling Fork at Bradfordsville, Summer 2008. *Source: LTADD Archive*.

The chart below outlines significant drought events in Kentucky since May of 1930. The Lincoln Trail Region lies within the Central region of the Commonwealth. The 2012 drought affected the entire State with PDSI ratings ranging from -0.5 to -3.99.

Table 3.3.2.9.2 - Significant Kentucky Drought Events			
Time Period	Location/Region	PDSI Rating	Crop Losses
May 1930 – December 1931	Bluegrass, Central, East, West	-4.73	NA
Fall 1939 – Spring 1942	Central, Bluegrass, East	-3.97	NA
Summer 1952 – Winter 1955	West, Bluegrass, Central	NA	NA
Summer 1996	West	NA	$154 million
Summer 2002	West	NA	$70 million
Summer 2007	Statewide	-2.75	Unknown
Fall 2008	Statewide	-2.75	Unknown
Spring/Summer 2012	Statewide	-0.5 to -3.99	Unknown
Source: NOAA, KY Energy and Environment Cabinet			

III. Analysis

To analyze drought as a hazard threat to the Lincoln Trail Region, research was done to determine what constitutes a drought and the far-reaching effects that it has. Historical events were researched and documented as well. Resources for information gathered include NOAA, the National Weather Service, the National Climatic Data Center, the National Drought Mitigation Center and the Commonwealth of Kentucky Energy and Environment Cabinet.
While drought events are not easily captured and reported, the table above is evidence of their occurrence. The back-to-back droughts of 2007 and 2008 were a hardship on local farmers and the 2012 drought adversely impacted the entire State.

Heat in concert with lack of precipitation often exacerbates drought conditions. The Kentucky Mesonet data below tracks maximum temperatures for the region over the last five years.

Table 3.3.2.9.3

Max Temperature Table for Lincoln Trail Region from 2016 to 2021 Source: Kentucky Mesonet							
Location	2016	2017	2018	2019	2020	2021 (through May 17)	Average
Breckinridge Co.	94.1	93.3	93.2	95.4	90.8	82.6	91.57
Grayson Co.	93.6	93.5	93.4	95.2	90.6	81.7	91.33
Hardin Co.	94.4	94	94.4	95.6	92.3	81.6	92.05
Larue Co.	91.9	91.6	93	95	89.9	81.1	90.41
Marion Co.	94.7	94.3	93.8	95.8	91.1	79.6	91.55
Meade Co.	92.5	92.4	93.1	95.3	91.5	80.9	90.95
Nelson Co.	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Wahsinton Co.	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average	93.53	93.18	93.48	95.38	91.03	80.98	91.31

Kentucky Mesonet data for local precipitation over the last five years is included below. The region will closely monitor and track Mesonet data to help track drought conditions specific to the eight-county area.

Table 3.3.2.9.4

Precipitation Data table for Lincoln Trail Region from 2016 to 2021 Source: Kentucky Mesonet							
Location	2016	2017	2018	2019	2020	2021 (through May 17)	Total
Breckinridge Co.	48.22"	54.47"	65.61"	61.2"	56.61"	22.2"	308.31"
Grayson Co.	55.7"	56"	60.65"	62"	61.09"	24.73"	320.17"
Hardin Co.	46.71"	56.04"	63.26"	60.29"	51.35"	20.01"	297.66"
Larue Co.	52.25"	53.69"	63.24"	60.54"	52.4"	22"	304.12"
Marion Co.	50.35"	43.86"	70.34"	61.48"	54.99"	21.96"	302.98"
Meade Co.	43.6"	50.5"	65.03"	59.05"	51.95"	20.5"	290.63"
Nelson Co.	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Wahsinton Co.	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average	49.47"	52.43"	64.68"	60.76"	54.73"	21.9"	

Table 3.3.2.9.6 Summary of Drought Index Data

Average Percentage of area in each drought category for each county, January 2016 to May 2021						
Location	None	Abnormally Dry (D0)	Moderate Drought (D1)	Severe Drought (D2)	Extreme Drought (D3)	Exceptional Drought (D4)
Breckinridge	91.5	8.5	5.23	2.17	0	0
Grayson	89.75	10.25	4.87	2.17	0	0
Hardin	90.79	9.12	5.13	2.38	0	0
Larue	88.61	11.39	5.05	2.22	0	0
Marion	88.4	11.6	4.65	2.29	0	0
Meade	91.18	8.18	5.21	2.07	0	0
Nelson	91.1	8.9	4.11	1.99	0	0
Washington	90.14	9.86	4.25	2.19	0	0
LTADD Average	90.18	9.72	4.81	2.18	0	0

Source: U.S. Drought Monitor (http://droughtmonitor.unl.edu/MapsAndData/DataTables.aspx)

Note: This data is based on the "Traditional Statistics" and may include multiple data in each category. It is possible to have a higher percent area for a higher category. Thus, it may exceed 100% for any given area. This data is over a very short time span, so it has limited use at this time to predict drought probability or correlate with any loss data. However, in the future further monitoring and data collection may yield more robust analysis.

3.3.2.10 Earthquakes

I. Background

According to the United State Geological Survey (USGS), an earthquake is "what happens when two blocks of the earth suddenly slip past one another. The surface where they slip is called the fault or fault plane. The location below the earth's surface where the earthquake starts is called the hypocenter, and the location directly above it on the surface of the earth is called the epicenter." This phenomenon results in a shaking, trembling, or concussion of the earth, often accompanied by a rumbling noise. The seismicity, seismism, or seismic activity of an area refers to the frequency, type and size of earthquakes experienced over a period of time.

At times, an earthquake will be preceded by a foreshock. A foreshock is smaller than an actual earthquake and will occur in the same place as the larger earthquake that follows. A foreshock cannot be identified as such until the larger earthquake has happened. The larger earthquake is called the mainshock and may be followed by aftershocks. Aftershocks are smaller earthquakes that follow a mainshock and can continue for weeks or months after the mainshock.

USGS explains "the earth has four major layers: the inner core, outer core, mantle and crust. The crust and the top of the mantle make up a thin skin on the surface of our planet. However, this skin is not all in one piece, it is made up of many pieces like a puzzle covering the surface of the earth. These pieces are slowly moving around, sliding past one another, and bumping into one another. These pieces are called tectonic plates, and the edges of the plates are called the plate boundaries. The plate boundaries are made up of many faults, and most of the earthquakes around the world occur in these faults. Since the edges of the plates are rough, they get stuck while the rest of the plate keeps moving. When the plate has moved far enough, the edges unstick on one of the faults and there is an earthquake."

When the edges of the fault are stuck together, the rest of the block keeps moving, and the energy that would normally allow the blocks to slide past one another is being stored up. The force of the moving blocks eventually overcomes the friction of the jagged edges of the faults and causes them to break apart. All of the stored-up energy is released and radiates outward from the fault in all directions as seismic waves. The seismic waves shake the ground as they move through it and as the waves reach the earth's surface, they shake the ground and anything on it.

Measuring Earthquakes

There are three scales for measuring the intensity of an earthquake. The *Mercalli scale* was invented in 1902 by Guiseppe Mercalli and uses observations of the people who experience the earthquake to estimate its intensity. This scale was subjective and dependent on the opinions of witnesses.

In 1934, Charles Richter developed the *Richter scale*. The Richter scale measured the magnitude of an earthquake using a formula based on amplitude of the largest wave recorded on a specific type of seismometer and the distance between the earthquake and the seismometer. Richter's scale was specific to earthquakes in California, but other scales, based on wave amplitudes and total earthquake duration, were developed for use in other situations and were consistent with Richter's scale.

The following chart compares equivalents for the Mercalli scale to the Richter scale and identifies some of the hazards associated with earthquakes.

Table 3.3.2.10.1 - Modified Mercalli Intensity Scale		
Mercalli Intensity	**Equivalent Richter Magnitude**	**Witness Observations**
I	1.0 to 2.0	Felt by very few people; barely noticeable.
II	2.0 to 3.0	Felt by a few people, especially on upper floors.
III	3.0 to 4.0	Noticeable indoors, especially on upper floors, but may not be recognized as an earthquake.
IV	4.0	Felt by many indoors. May feel like heavy truck passing by.
V	4.0 to 5.0	Felt by almost everyone, some people awakened. Small objects moved, trees and poles may shake.
VI	5.0 to 6.0	Felt by everyone. Difficult to stand. Some heavy furniture moved, some plaster falls. Chimneys may be slightly damaged.
VII	6.0	Slight to moderate damage in well-built ordinary structures. Considerable damage to poorly built structures. Some walls may fall.
VIII	6.0 to 7.0	Little damage in specially built structures. Considerable damage to ordinary buildings, severe damage to poorly built structures. Same walls collapse.
IX	7.0	Considerable damage to specially built structures, buildings shifted off foundations. Ground cracked noticeably. Wholesale destruction. Landslides.
X	7.0 to 8.0	Most masonry and frame structures and their foundations destroyed. Ground badly cracked. Landslides. Wholesale destruction.
XI	8.0	Total damage. Few, if any structures standing. Bridges destroyed. Wide cracks in ground. Waves seen on ground.
XII	8.0 or greater	Total damage. Waves seen on ground. Objects thrown up into the air.
Source: Michigan Technological University		

As the chart below illustrates, earthquakes are also categorized ranging from minor to great, depending on magnitude.

Table 3.3.2.10.2 - Earthquake Magnitude Classes	
Class	**Magnitude**
Great	8 or more
Major	7.0 – 7.9
Strong	6.0 – 6.9
Moderate	5.0 – 5.9
Light	4.0 – 4.9
Minor	3.0 – 3.9
Source: Michigan Technological University	

Table 3.3.2.10.3 - Earthquake Magnitude Scale		
Magnitude	**Earthquakes Effects**	**Estimated Number Each Year**
2.5 or less	Usually not felt but can be recorded by seismograph.	900,000
2.5 to 5.4	Often felt, but only causes minor damage.	30,000
5.5 to 6.0	Slight damage to buildings and other structures.	500
6.1 to 6.9	May cause a lot of damage in very populated areas.	100
7.0 to 7.9	Major earthquake. Serious Damage.	20
8.0 or greater	Great earthquake. Can totally destroy communities near the epicenter.	One every 50 to 10 years
Source: Michigan Technological University		

The newest scale for measuring the magnitude of an earthquake is the **Moment Magnitude Scale**. The moment magnitude scale is based on the total moment release of the earthquake. Moment is a product of the distance a fault moved, and force required to move it. The moment magnitude scale estimates are about the same as Richter magnitudes for small and large earthquakes, but only the moment magnitude scale is capable of measuring M8 (read 'magnitude 8') and greater events accurately.

Causes/Prevention of Earthquakes

Earthquakes occur naturally due to the makeup of the earth and the constant movement that takes place between its tectonic plates. These quakes cannot be predicted ahead of time. However, scientists have mapped the major fault lines in the world and know where the greatest likelihood of an earthquake will occur.

While we cannot prevent natural earthquakes from occurring, we can significantly mitigate their effects by identifying hazards, avoid building structures in hazardous areas, building safer structures, and educating the public on earthquake safety. Earthquakes caused by human activity have been documented in the United States and various locations around the world. Earthquakes resulting from human activity include impoundment of reservoirs, surface and underground mining, withdrawal of fluids and gas from the subsurface, and the injection of fluids into underground formations. Most man-made earthquakes are small and present little hazard, larger and potentially damaging man-made earthquakes have occurred in the past.

Hazards, resulting from man-made earthquakes, can be mitigated by minimizing or eliminating the human activity that causes them.

Effects of Earthquakes

The effects of earthquakes include, but are not limited to, the following:

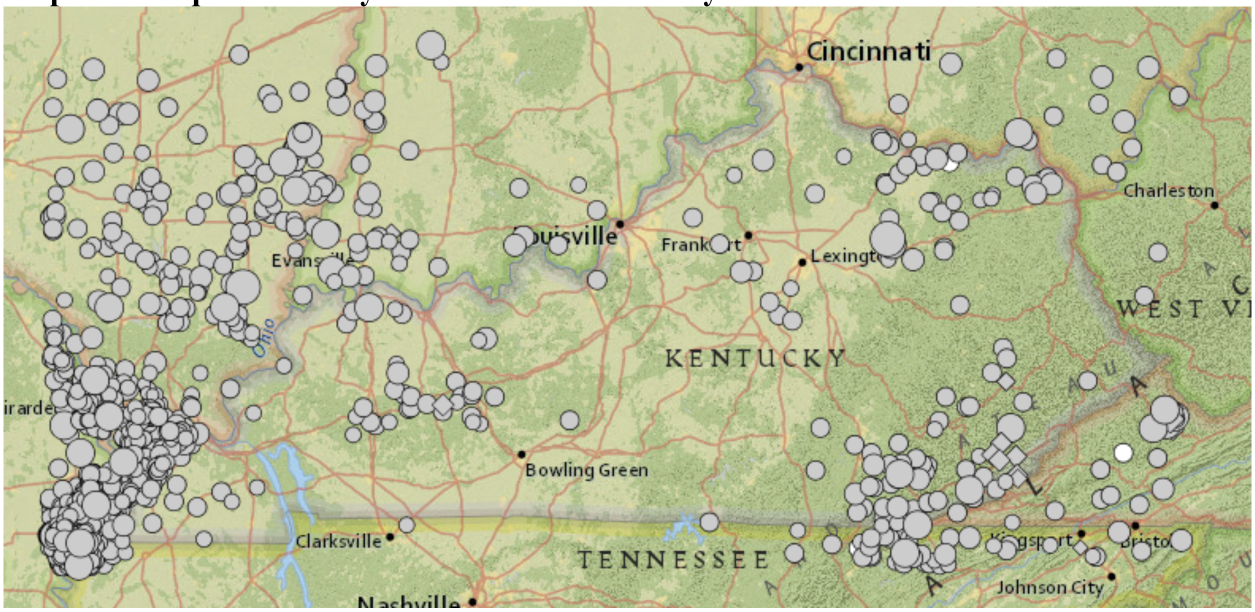
- Shaking and ground rupture are the main effects of an earthquakes. This will result in damage to buildings and other rigid structures. The severity of the local effect will depend on the complex combination of the earthquake magnitude, the distance of the site from the epicenter, and the local geological and geomorphological conditions, which may amplify or reduce wave propagation. The degree of ground shaking is measured by ground acceleration. Ground rupture is a major risk for large engineering structures such as dams, bridges, and nuclear power stations.
- Fires can result from earthquakes when shaking or ground rupture damages electrical power or gas lines. When water mains rupture as the result of an earthquake, it becomes very difficult to stop the spread of fire once it is started.
- Landslide and avalanches can be the effect of an earthquake when the quake results in slope instability.
- Soil liquefaction occurs when shaking, water-saturated granular material (such as sand) temporarily loses its strength and changes from a solid form into a liquid. This can cause structures to sink into the ground and collapse upon themselves.
- Tsunamis are long-wavelength, long-period sea waves produced by the sudden or abrupt movement of large volumes of water. This can occur when an earthquake takes place under a sea or other large body of water. Large waves produced by an earthquake can overrun nearby coastal areas in a matter of minutes. Tsunamis can also travel thousands of kilometers across open-ocean and wreak destruction on far shores hours after the earthquake that generated them.
- Floods may be a secondary effect of earthquakes if dams are damaged or destroyed. Earthquakes may also cause landslips to dam rivers, which collapse and cause floods.
- Human impacts because of an earthquake include injury and loss of life, road and bridge damage, general property damage, and collapse or destabilization of buildings. The aftermath of an earthquake may bring disease, lack of necessities and higher insurance premiums.

II. Profile

Kentucky Earthquake History

Most earthquake activity in Kentucky has occurred in the western portion of the State near the New Madrid seismic zone. As early as 1779, 1791 and 1792 earthquake activity were recorded in the northern and eastern portions of Kentucky. Between 1811 and 1812, about 2,000 to 3,000 tremors were felt in Kentucky from an initial shock on December 16, 1811.

Map of earthquake activity in and around Kentucky 1901-2021

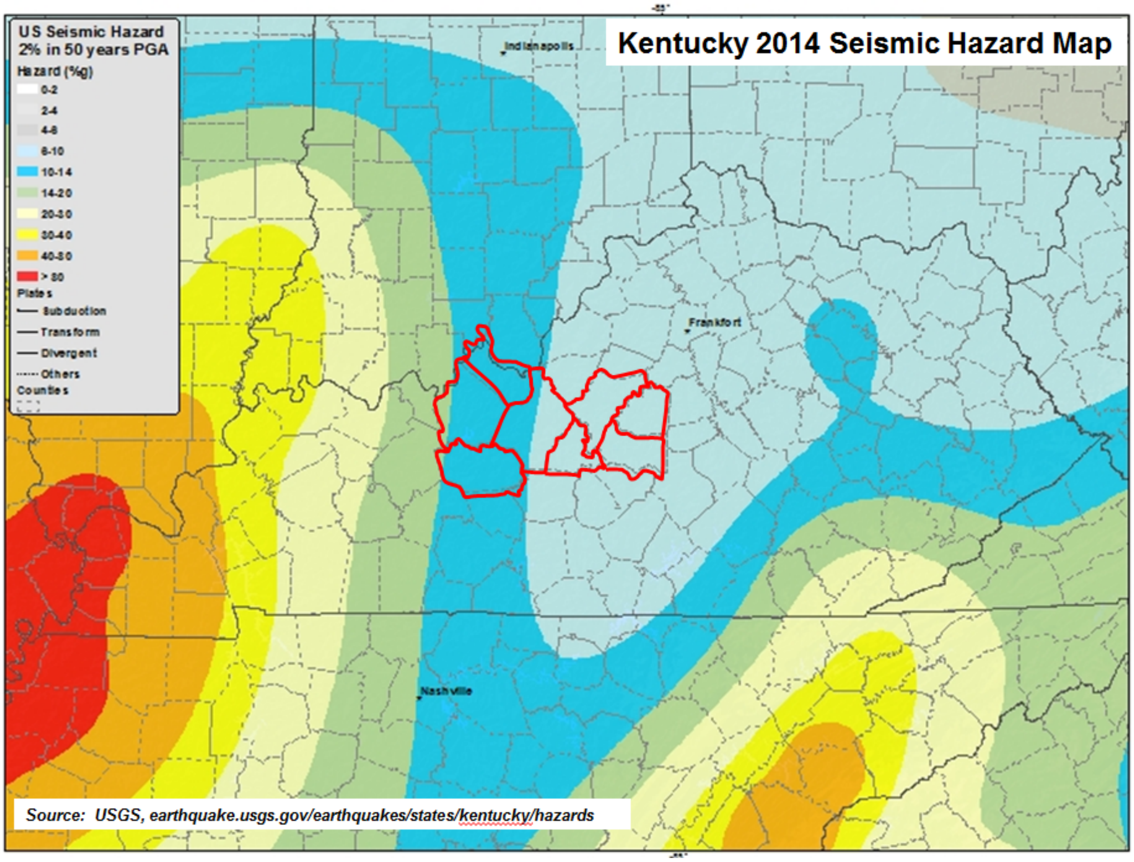


Source: USGS

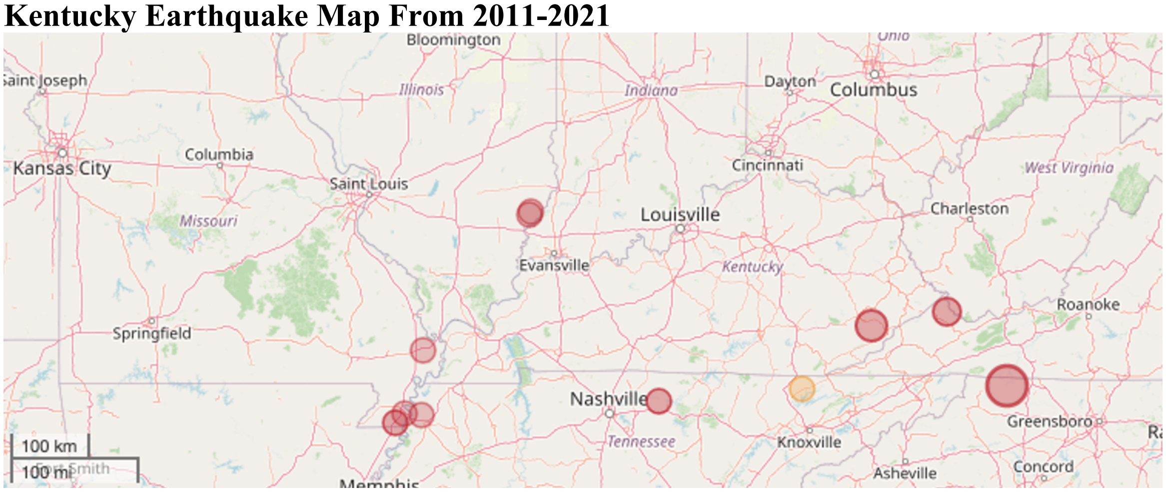
Over the next 100 years, a few moderate earthquakes occurred in the State. A shock at Columbus, Kentucky on March 12, 1878, caused a section of bluff on the Mississippi River to cave in. On October 26, 1915, an earthquake at Mayfield was reported to have shaken pictures from walls. A sharp earthquake, with an epicenter near the mouth of the Ohio River, occurred on December 7, 1915, and shook western Kentucky and adjoining regions. It was an intensity V to VI and was felt over an area of 60,000 square miles.

Other earthquake events were recorded in 1841, 1916, 1915 and 1924. About 75,000 square miles of land in Kentucky, Illinois, Indiana, and Tennessee were affected by an earthquake, on September 2, 1925. The epicenter of the quake was near Henderson and landslides were noted in

Slight damage was reported near Middlesboro Kentucky as the result of an intensity V earthquake on January 1, 1954. The earthquake that occurred on November 9, 1968, was measured as an intensity VII, and did considerable masonry damage at the City Building in Henderson, Kentucky which was about 50 miles east, southeast of the epicenter. On January 20, 2020, a 3.8 magnitude earthquake with its epicenter in Tennessee could be felt 40 miles away in parts of eastern Kentucky. Earthquakes in Kentucky are common, but they are often not strong enough to be felt. the damage reports. At Louisville, about 100 miles away, a chimney fell, and a house reportedly sank.



Kentucky Earthquake Map From 2011-2021



Source: volcanicdiscovery.com

III. Analysis

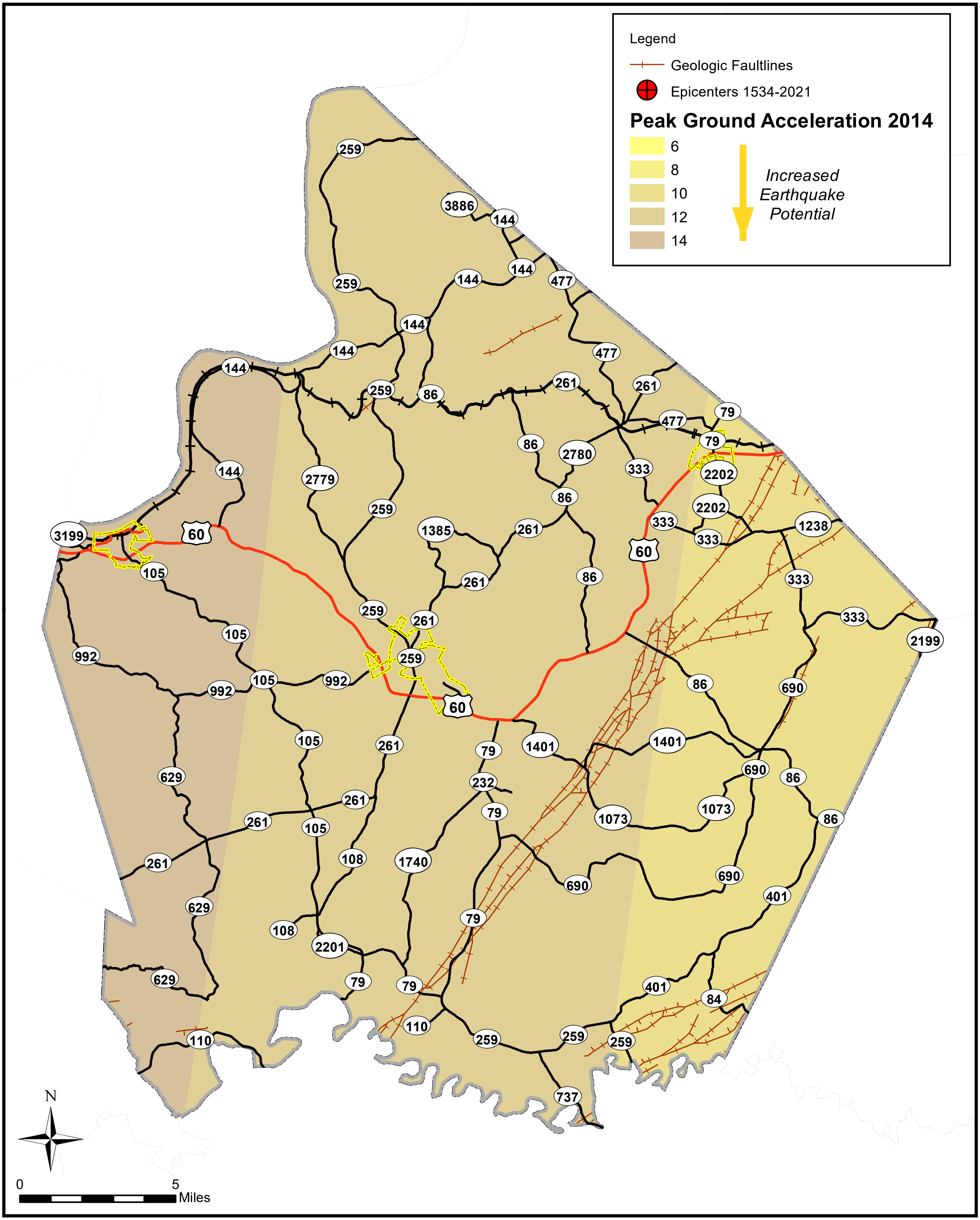
The data below is from the United States Geological Survey and depicts the chance of a major earthquake (5.0 to 9.2) in each of the Lincoln Trail Region's eight counties within a 50km area, within the next 50 years.

Table 3.3.2.10.4 - Earthquake Chance for the Lincoln Trail Region Counties	
County	**Chance of Major Earthquake within Next 50 years**
Breckinridge	1.09%
Grayson	0.73%
Hardin	0.50%
LaRue	0.30%
Marion	0.30%
Meade	0.83%
Nelson	0.39%
Washington	0.41%
Source: USGS Database	

There is little likelihood that any part of the Lincoln Trail Region will experience a disaster because of an earthquake. However, the region must plan preparedness measures, and mitigate hazards by educating the public on earthquakes, using wise land use guidelines and by avoiding activities that increase the chance of creating a man-made earthquake.

There have been no recorded earthquakes with its epicenter in the region since the 2010 update was published per USGS. Source: earthquake.usgs.gov/earthquakes/search.

The following maps illustrate the few documented historic earthquakes that have had their epicenter in the Lincoln Trail Region. It also shows the potential for future events by portraying the Peak Ground Acceleration (PGA) values in shades of yellow and alluvial soils that have a higher potential for liquefaction. The PGA in the region decreases from west to east. The faults that exist in the Region are very old and inactive but are portrayed on the map by the black, ticked lines for reference.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Geologic Faultlines
Epicenters 1534-2021
Peak Ground Acceleration 2014
6
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Increased Earthquake Potential
259
3886
144
477
261
86
79
2780
333
2202
1238
2779
1385
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105
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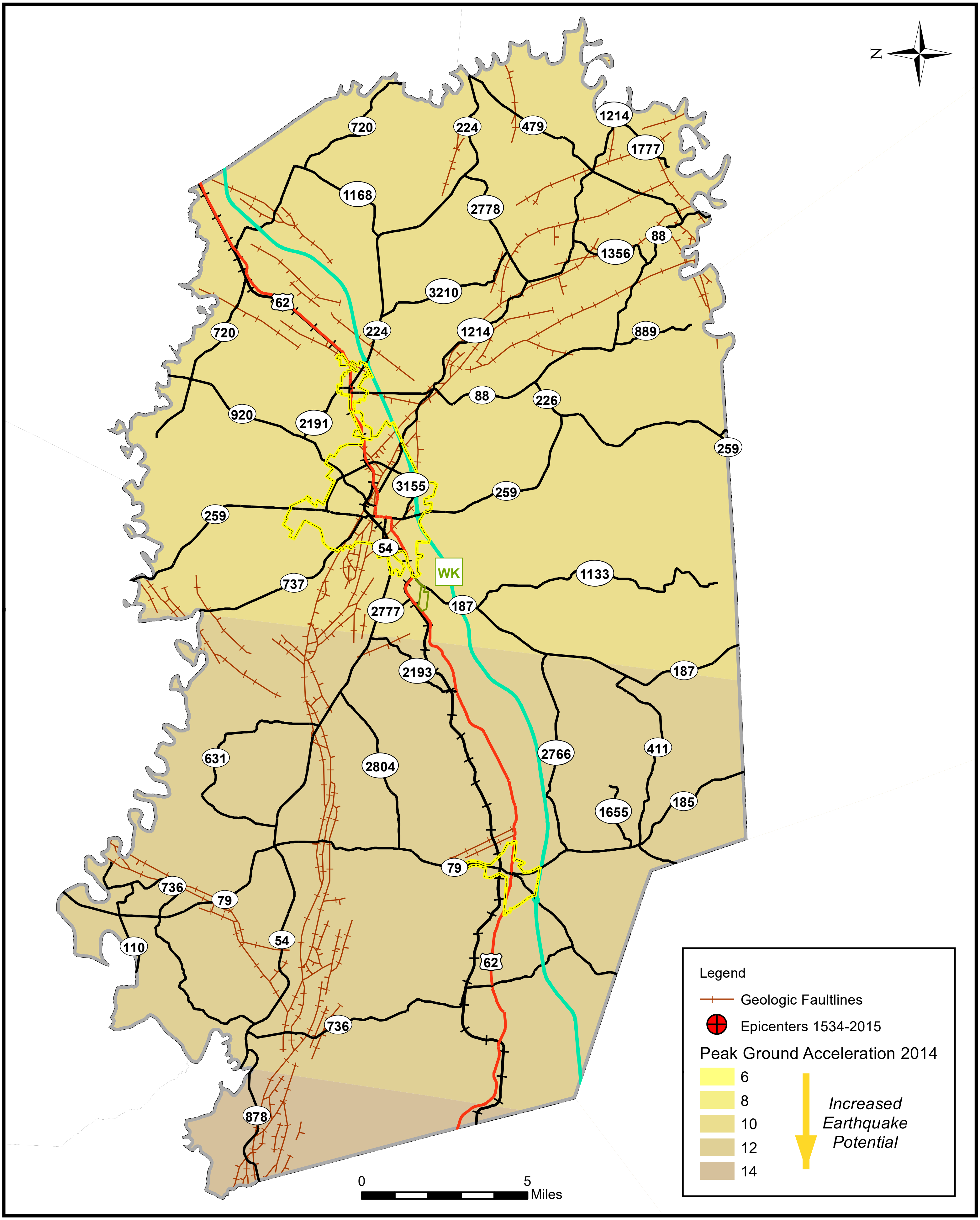
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3155
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259
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Peak Ground Acceleration 2014
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Earthquake
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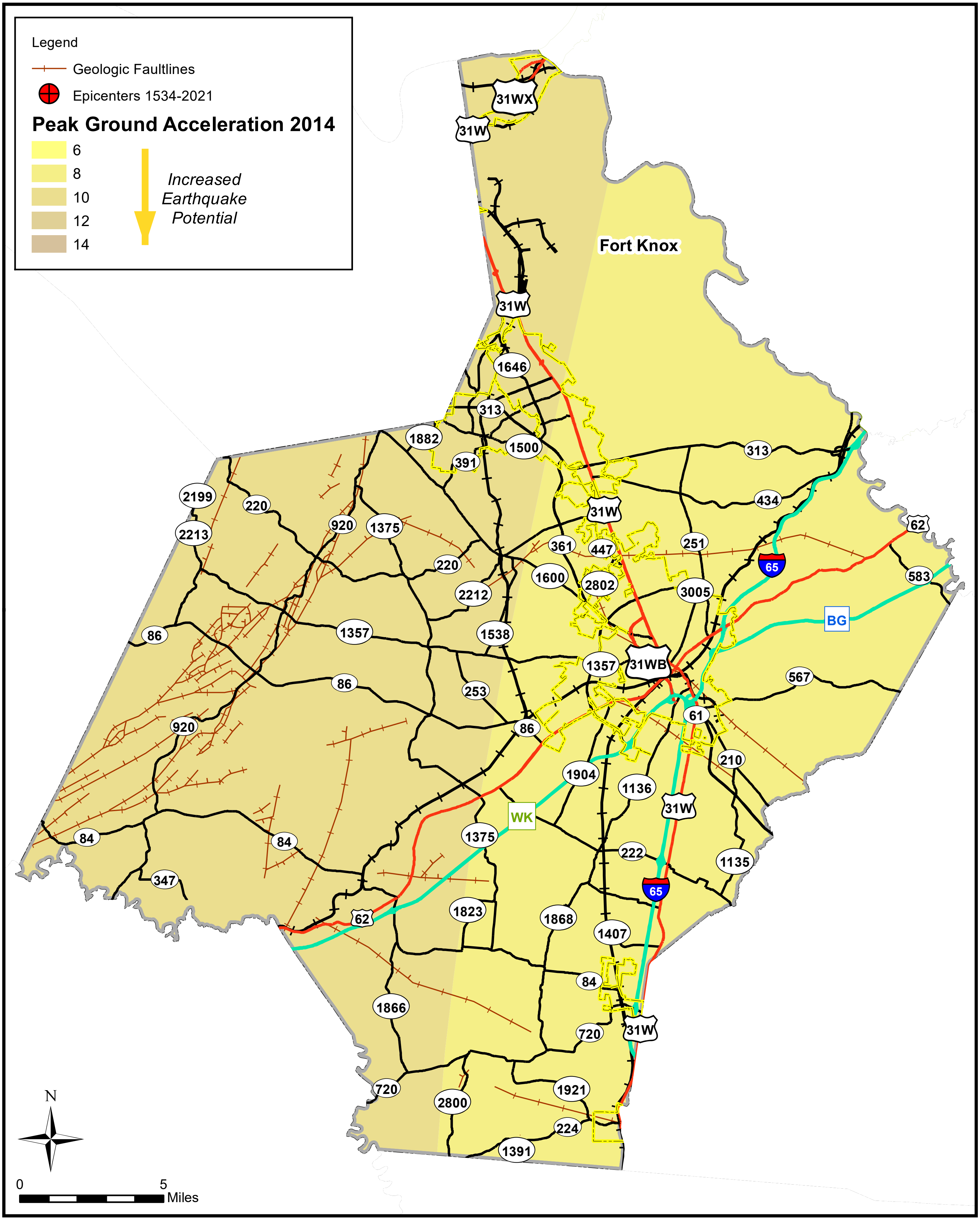
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Geologic Faultlines
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Increased Earthquake Potential
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1882
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391
434
31W
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920
1375
2213
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447
251
62
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2212
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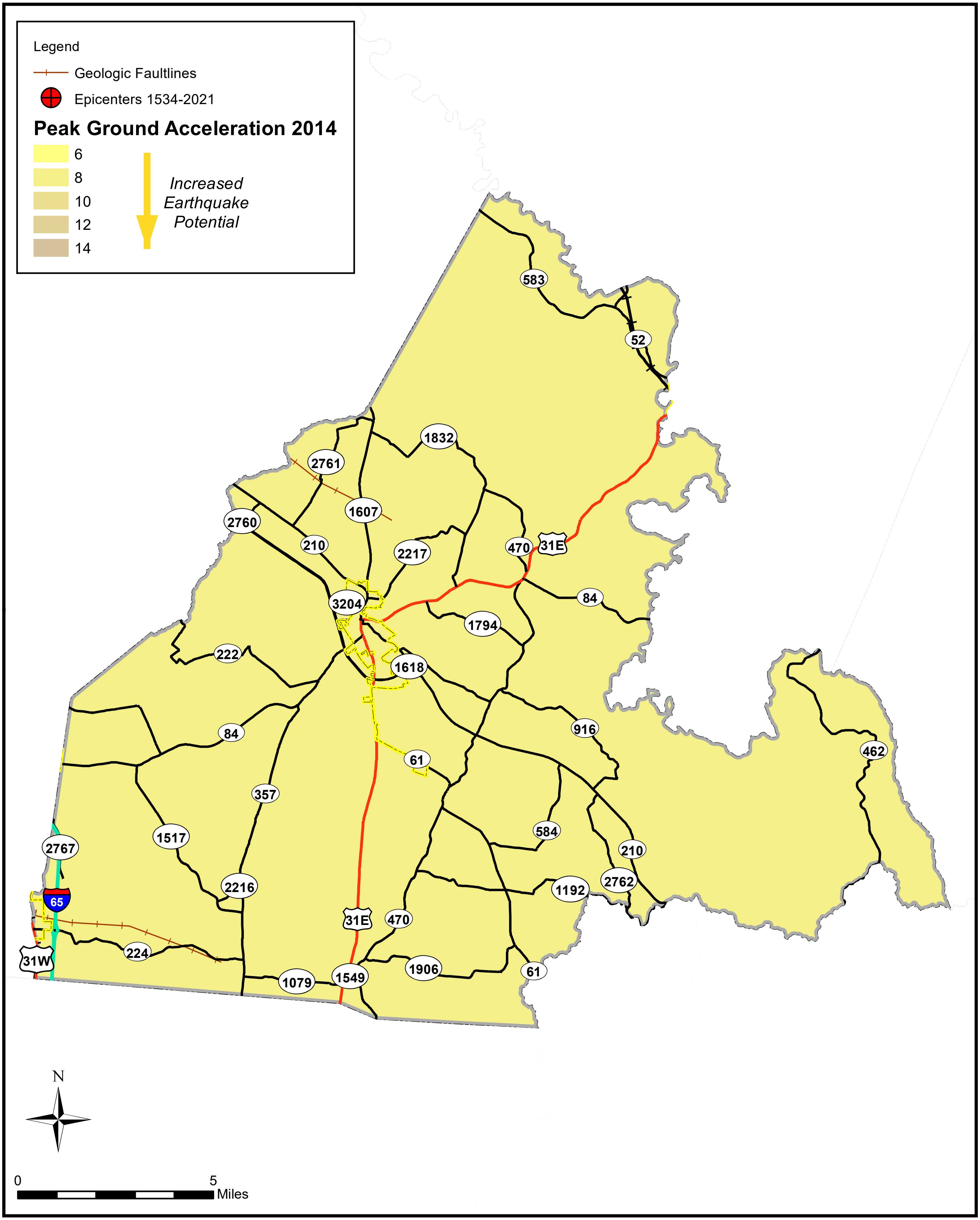
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Increased Earthquake Potential
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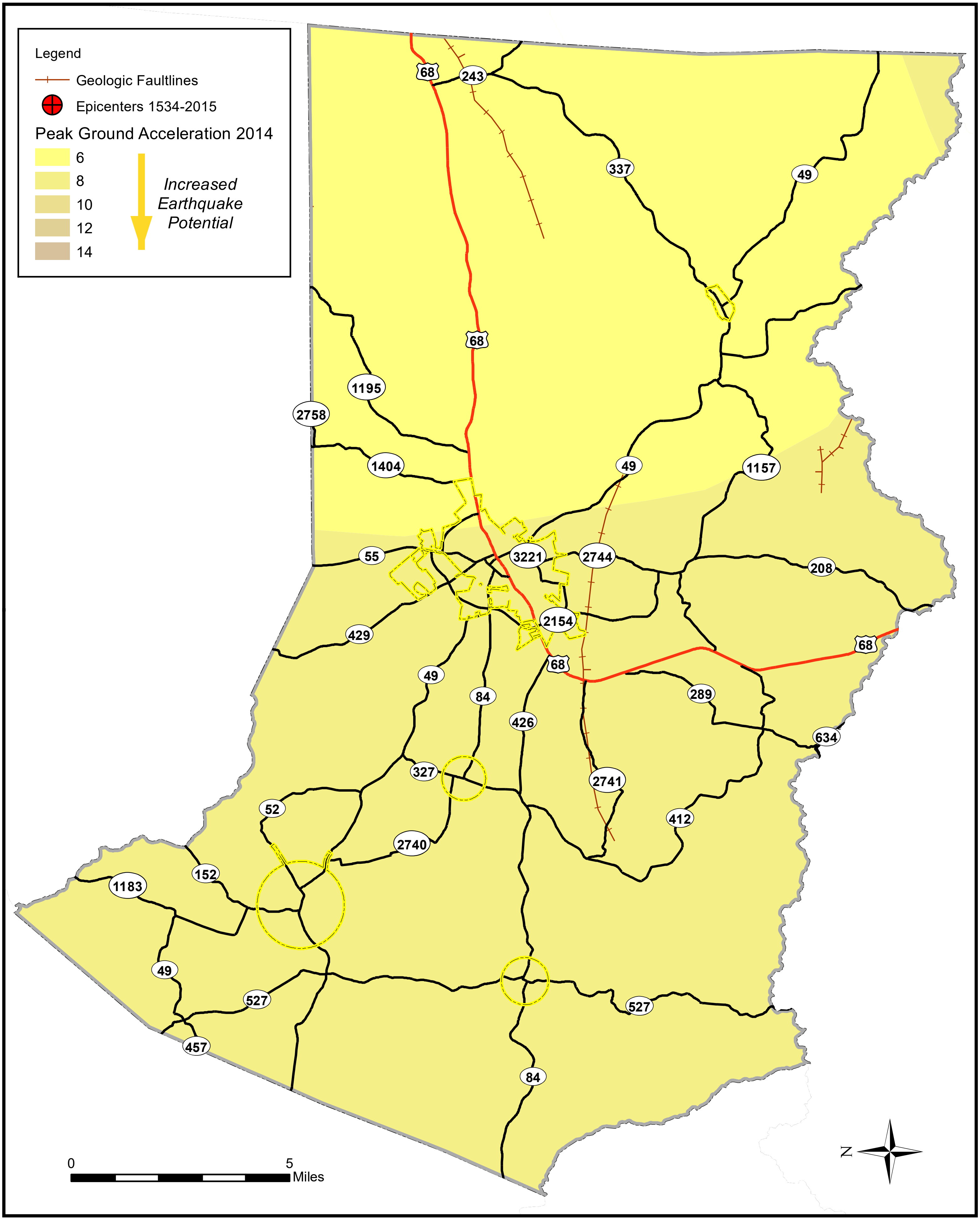
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Increased Earthquake Potential
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68
49
84
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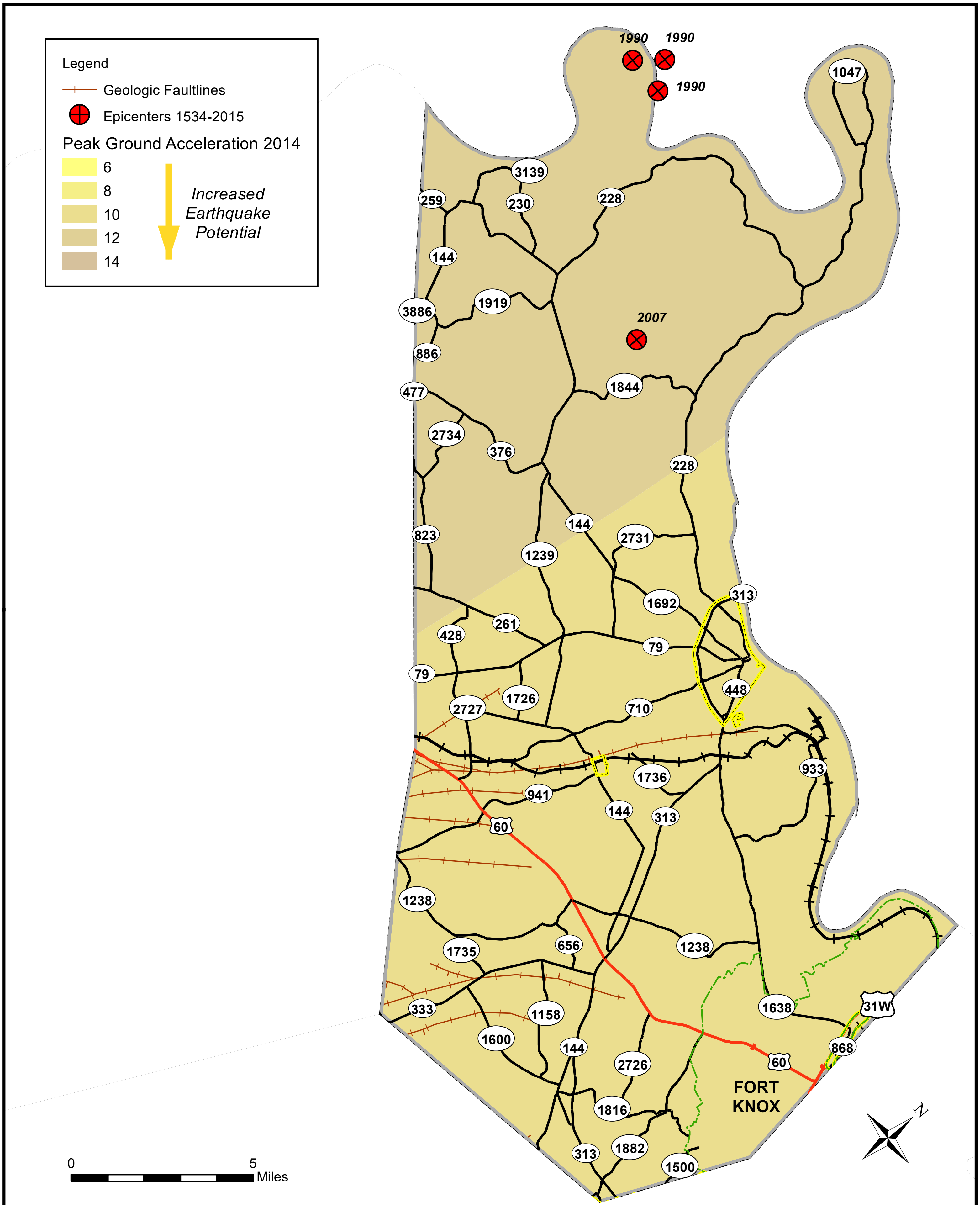
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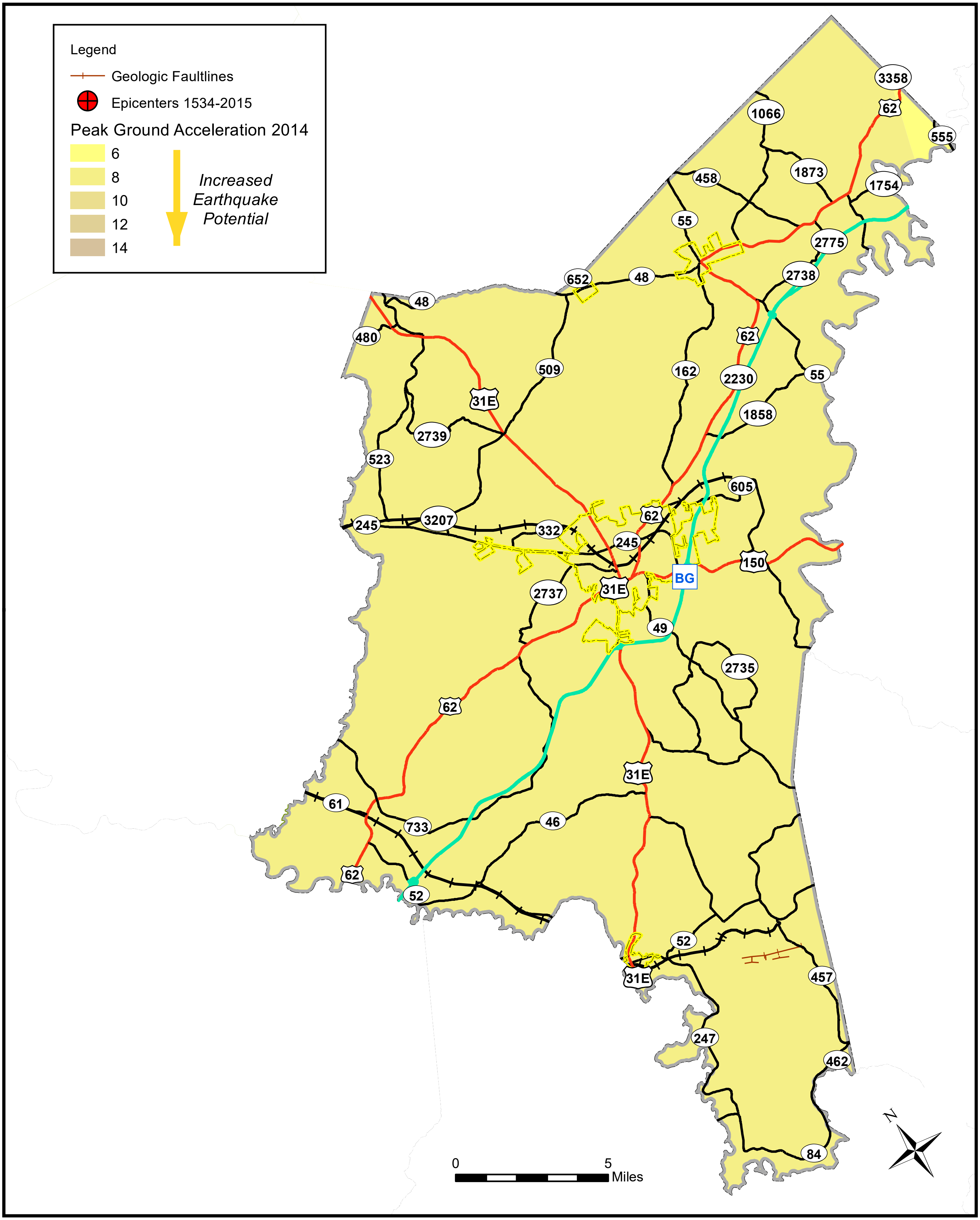
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Epicenters 1534-2015
Peak Ground Acceleration 2014
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1754
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2775
652
48
2738
48
480
62
509
162
2230
55
31E
1858
2739
523
605
62
245
3207
332
245
150
BG
2737
31E
49
2735
62
31E
61
733
46
62
52
52
31E
457
247
462
84
0
5
Miles
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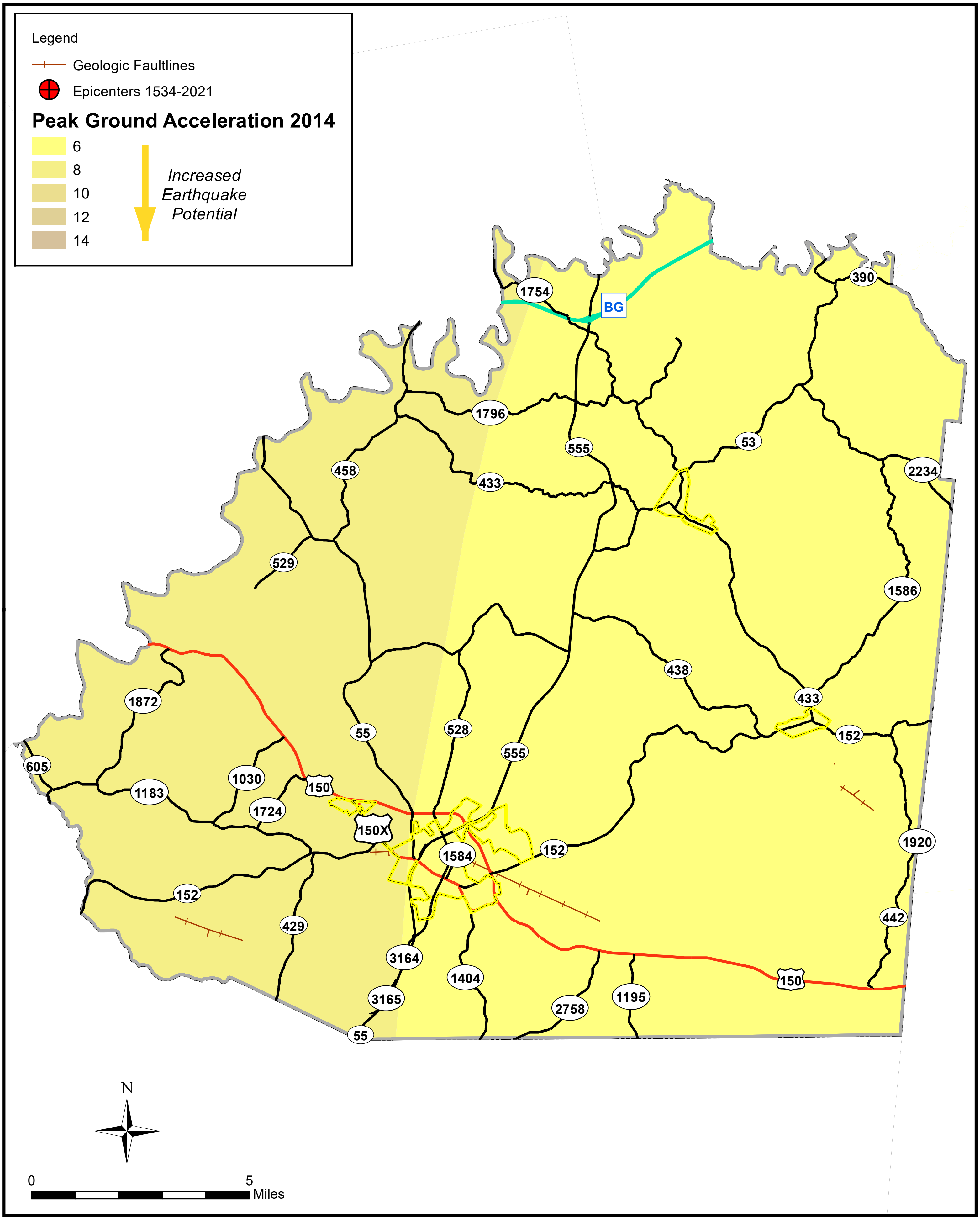
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Geologic Faultlines
Epicenters 1534-2021
Peak Ground Acceleration 2014
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Increased Earthquake Potential
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390
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3.3.2.11 Hurricane

I. Background

Merriam-Webster defines a hurricane as "an extremely large, powerful and destructive storm with very strong winds that occurs especially in the western part of the Atlantic Ocean." Typically, a hurricane is considered a tropical storm with winds of 74 miles per hour or greater. The storm or cyclone is accompanied by rain, thunder, and lightning.

Hurricanes are unique. Unlike any other storms on earth, hurricanes can be viewed from space as powerful, tightly coiled weather systems. Also called cyclones; the general term for all circulating weather systems, the storms move counterclockwise in the Northern Hemisphere over tropical waters. There are three classes of tropical cyclones:

1. **Tropical Depression** - A tropical depression is an organized system of clouds and thunderstorms with a defined circulation and maximum sustained winds of 38 mph or less.

2. **Tropical Storm** - A tropical storm is an organized system of strong thunderstorms with a defined circulation and maximum sustained wind of 39 to 73 mph.

3. **Hurricane** - A hurricane is an intense tropical storm with a well-defined circulation and maximum sustained winds of 74 mph or greater. In the western Pacific, hurricanes are called typhoons," and similar storms in the Indian Ocean are called cyclones.

The National Atmospheric and Oceanic Agency (NOAA) further defines the attributes of a hurricane. "Hurricanes are products of the tropical oceans and atmosphere. Powered by heat from the sea, they are steered by the easterly trade winds and the temperate westerlies, as well as by their own ferocious energy. Around their core, winds grow with great velocity, generating violent seas. Moving ashore, they sweep the ocean inward while spawning tornadoes and producing torrential rains and floods. Each year on average, ten tropical storms (of which six become hurricanes) develop over the Atlantic Ocean, Caribbean Sea, or Gulf of Mexico. Many of these remain over the ocean. However, about five hurricanes strike the United States coastline every 3 years. Of these five, two will be major hurricanes (category 3 or greater on the Saffir-Simpson Hurricane Scale)."

Saffir-Simpson Hurricane Scale and Associated Damages

The intensity of a hurricane is measured by 5 categories. The following scale provides examples of the impacts and damages associated with each category in the United States.

Table 3.3.2.11.1 - Saffir-Simpson Hurricane Wind Scale		
Category	**Wind Speed (mph)**	**Damage**
1	74 - 95	Very dangerous winds will produce some damage
2	96 - 110	Extremely dangerous winds will cause extensive damage
3	111 - 129	Devastating damage will occur
4	130 - 156	Catastrophic damage will occur
5	> 156	Catastrophic damage will occur
Source: NOAA - National Hurricane Center		

II. Analysis

Hurricanes in Kentucky

Although catastrophic damage can result from hurricanes, the geographic location of the Lincoln Trail Region and Kentucky precludes the State from experiencing this level of damage.

However, in September of 2008, Hurricane Ike caused widespread damage across eleven states including Arkansas, Illinois, Indiana, Kentucky, Michigan, Missouri, New York, Ohio, Pennsylvania, Tennessee, and West Virginia. Although the storm made landfall in Texas and Louisiana, the effects were even felt in parts of Ontario due to the incredible strength and size of Ike.

In Kentucky, the Louisville area declared a state of emergency due to major damage, and the Louisville International Airport was temporarily closed. A utility spokesperson indicated that the area suffered its worst power outage in 30 years as a result of Ike. Near Covington, the Cincinnati – Northern Kentucky International Airport was also temporarily closed, and the control tower evacuated. An apartment building in Covington also lost its entire roof. The Kentucky Governor declared a statewide state of emergency and many schools were closed or delayed in the first 3 days following the storm. Statewide, over 600,000 customers lost electricity because of the winds, and a boy was struck and killed by a blown tree limb in Simpsonville. In the time since these events there have been no hurricane events that have had major weather-related effects on the state.

3.3.2.12 <u>Tsunami</u>

I. Background

The Nation Oceanic and Atmospheric Administration defines a tsunami as "a series of ocean waves generated by sudden displacements in the sea floor, landslides, or volcanic activity. In the deep ocean, the tsunami wave may come gently ashore or may increase in height to become a fast-moving wall of turbulent water several meters high."

While a tsunami cannot be mitigated, the impact of a tsunami can be mitigated through public education, community preparedness, timely warnings, and effective response efforts.

Tsunami waves do not resemble normal sea waves. Instead of appearing as a normal breaking wave, a tsunami may initially resemble a rapidly rising tide. Tsunamis usually consist of a series of waves with periods ranging from minutes to hours, arriving in a "wave train." The height of waves can be tens of meters in large events. The impact of tsunamis is limited to coastal areas, but their destructive force can be disastrous and may affect entire ocean basins.

II. Analysis

Due to the geographic location of Kentucky and the eight-county Lincoln Trail Region, tsunamis do not pose a threat to Kentucky jurisdictions.