Risk Assessment of Sudden Sinkhole Formation in St. Louis, Missouri

Background

Population growth in areas underlain by soluble bedrock presents a unique problem for urban planners. Increased stress from development in these areas often results in a higher propensity for sinkhole formation. Sinkholes are closed topographic depressions resulting from the settlement or collapse of soil or rock into solution openings beneath the ground surface. They can vary in size, but the most hazardous sinkholes can be large enough to swallow houses and roads, causing millions of dollars in damages and sometimes death.

Image obtained from: http://www.jkeassociates.com/admin/photos/

Photo courtesy of Doug Gouzie, 2006

Though sinkhole formation can be a steady process with subsidence occurring slowly over time, urban planners need to focus on the possibility of sudden sinkhole collapse. This type of sinkhole formation is unexpected and often results in the most damage to humans as well as the environment through sinkhole flooding and deterioration in groundwater quality.

Since about 66 to 75 percent of sinkholes are induced by activity like groundwater pumping and changes in surface drainage, planning decisions must be carefully considered in order to avoid and minimize the risk of sinkhole development. At the same time, if an area is already developed but located on known sinkhole terrain, planners must determine locations of highest risk of sinkhole collapse so that those areas can be closely monitored. Therefore, it is imperative to understand the factors associated with sudden sinkhole formation so that environmental protection procedures can be implemented at all stages of the development process.

Purpose

The purpose of this project is to perform a sinkhole risk assessment for the city of St. Louis, Missouri. Missouri, along with Kentucky, Florida, Texas, Alabama, and Tennessee, are known for large populations of sinkholes. Areas within St. Louis with the highest sinkhole risk will be located by combining 6 factors that are commonly involved in sudden sinkhole formation. These factors include **1)carbonate bedrock, 2)high cave density, 3)high current sinkhole density, 4)high overburden thickness, 5)low groundwater elevation, and 6)high slope**. The areas with the highest propensity for sudden sinkholes will be those with the highest value of combined factors. The social and planning implications of the results will be discussed.

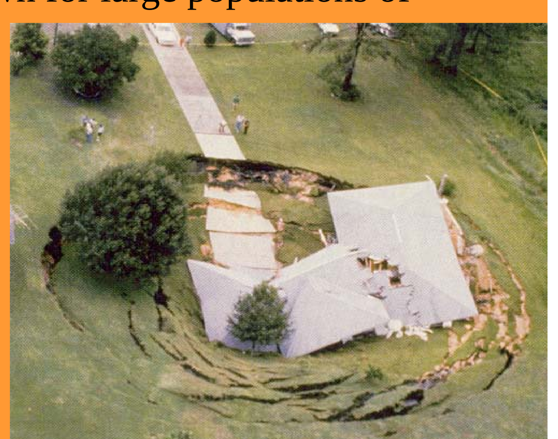


Image obtained from: http://mail.colonial.net/~hkaiter/scienceimagesB/

Methodology

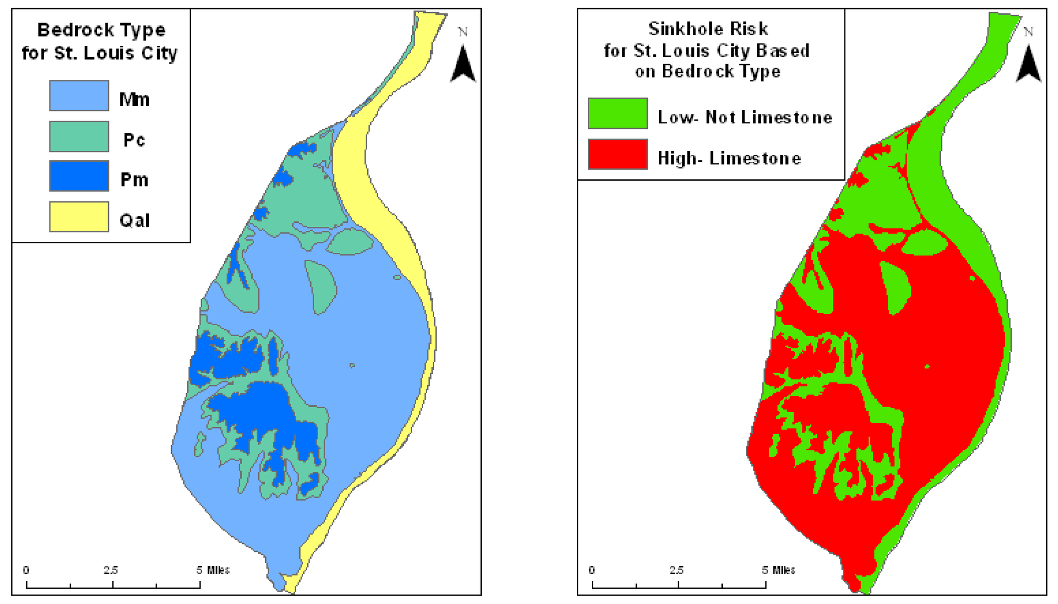
The methodology of this project generally followed three steps. For each sinkhole risk factor:

1. Data was converted from vector to raster format.
2. Data was reclassified using 'Equal Intervals' to follow a ranking system where a higher number = a higher sinkhole risk.
3. The 6 reclassified risk factors were added together with equal and varying weights.

Risk Factor	Equal Weights	Varying Weights
Bedrock	1	0.25
Cave Density	1	0.25
Current Sinkhole Density	1	0.25
Overburden Thickness	1	0.08
Groundwater Elevation	1	0.09
Slope	1	0.08

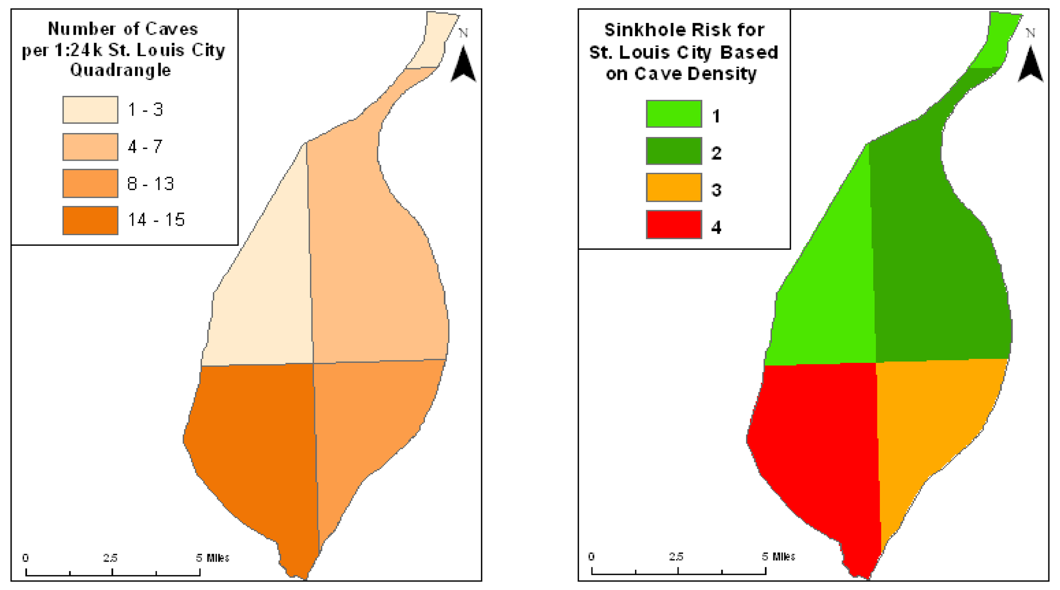
Risk Factor 1: Bedrock

According to the USGS, areas of St. Louis built on top of limestone and other carbonate rocks are at a high risk for sinkhole formation. These rock groups, also referred to as karst, weather over long periods of time leading to the creation of large caverns below the surface. If the land above these underground spaces is no longer supported, sudden collapse may occur. The USGS indicates that the Pennsylvanian Marmaton Group (Pm) and the Mississippian Meramecian Series (Mm) are both primarily limestone. During reclassification, these areas were reclassified as having a higher risk.



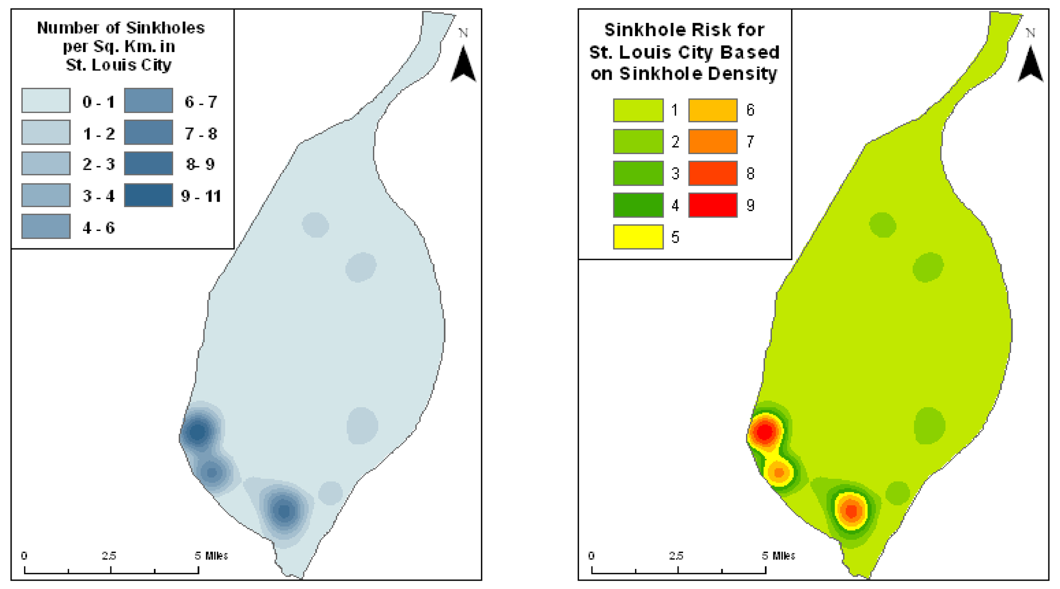
Risk Factor 2: Cave Density

Sinkhole formation is closely associated with underground caves. These caves are often the result of limestone bedrock that has been dissolved by groundwater. When the roof of a cave near the surface can no longer bear the weight of overburden, sinkholes will form. Therefore, areas in St. Louis, Missouri with a higher cave density are at a greater risk for sinkhole formation and were reclassified with higher risk values. Since cave density data for St. Louis is only available by quadrangle, the resulting map shows the average cave density per 1:24K Missouri quadrangle.



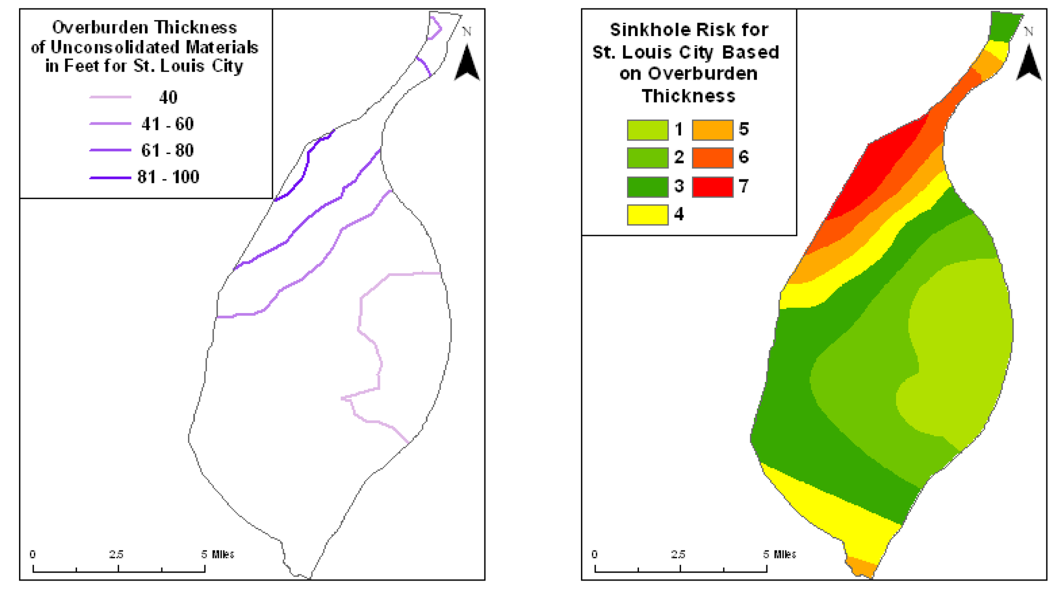
Risk Factor 3: Sinkhole Density

Areas in St. Louis with greater numbers of current sinkholes are at a higher risk for future sinkholes. In order to find the areas in the city with the highest number of current sinkholes, a sinkhole density map was created using the location of known sinkholes with a search radius of 1500 square kilometers. Those areas with the largest number of sinkholes per square kilometer were reclassified with a higher risk number.



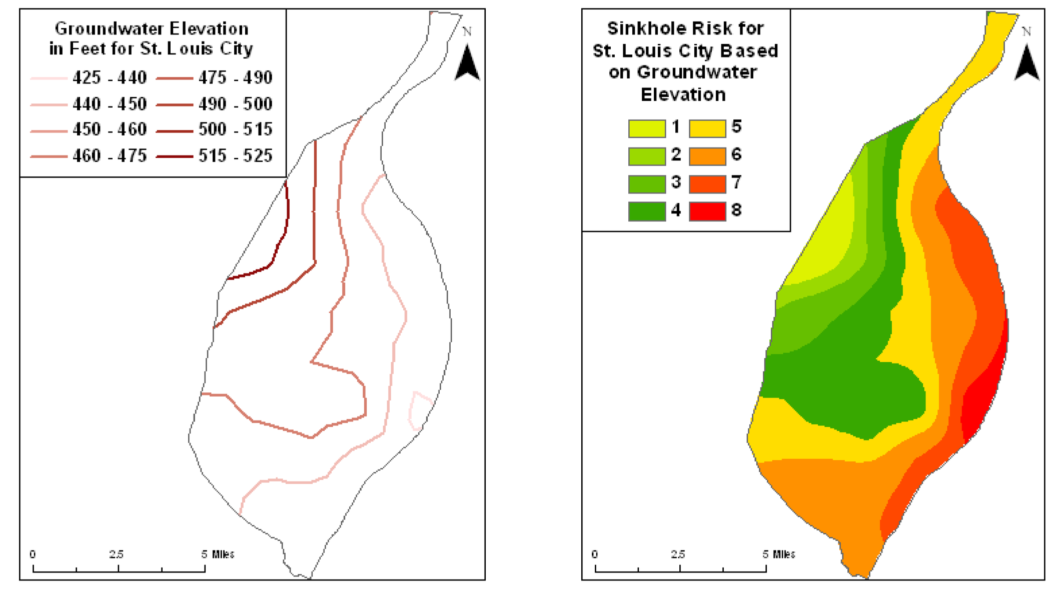
Risk Factor 4: Overburden Thickness

Overburden refers to soil, clay, sand and other unconsolidated material that lies above a specific geologic feature of interest. When overburden is thick, it creates a 'false roof' effect over dissolving bedrock since it can support structures like houses for longer periods of time. It will collapse suddenly when spalling of sediments leads to a weakening of the structural arch. Thinner overburden allows for slower dissolution and slower subsidence that occurs over a 50-100 year period. Therefore, thicker overburden is a higher risk factor for sudden sinkhole formation and was reclassified with higher risk values.



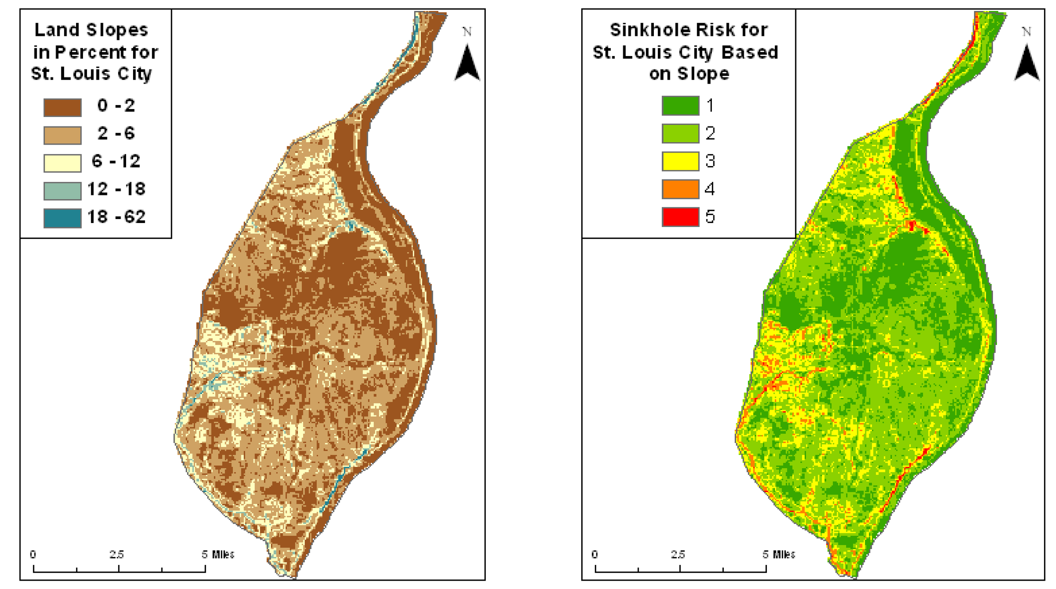
Risk Factor 5: Groundwater Elevation

One human induced cause for sinkhole collapse is the pumping of groundwater. Intense and prolonged groundwater pumping causes large drawdowns in aquifers. This lowering in hydraulic head results in underground spaces becoming more susceptible to collapse due to a loss of pore pressure and increased weathering of the bedrock. Therefore, areas in St. Louis with lower groundwater elevation are at a higher risk for sudden sinkhole collapse and were reclassified with larger risk numbers.



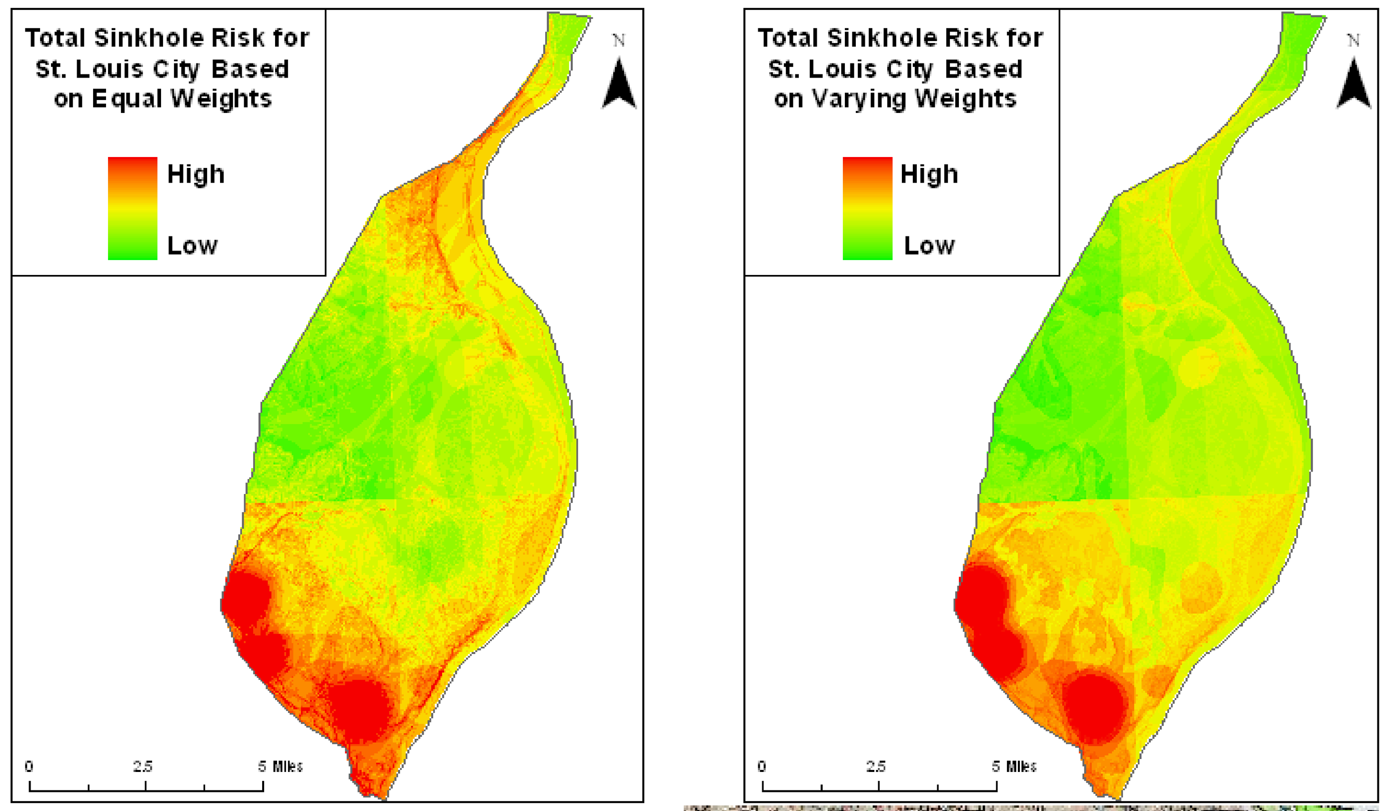
Risk Factor 6: Land Slope

Land slope relates directly to groundwater recharge and thus groundwater elevation. Areas with a higher slope have a greater propensity for runoff than recharge, leading to lower groundwater elevation, and a higher potential for sinkhole formation. A digital elevation model for the city was converted using the Spatial Analyst tool to show land slopes in percent. The percent classes were determined based on previous research[1] and higher percents were reclassified with higher risk values.



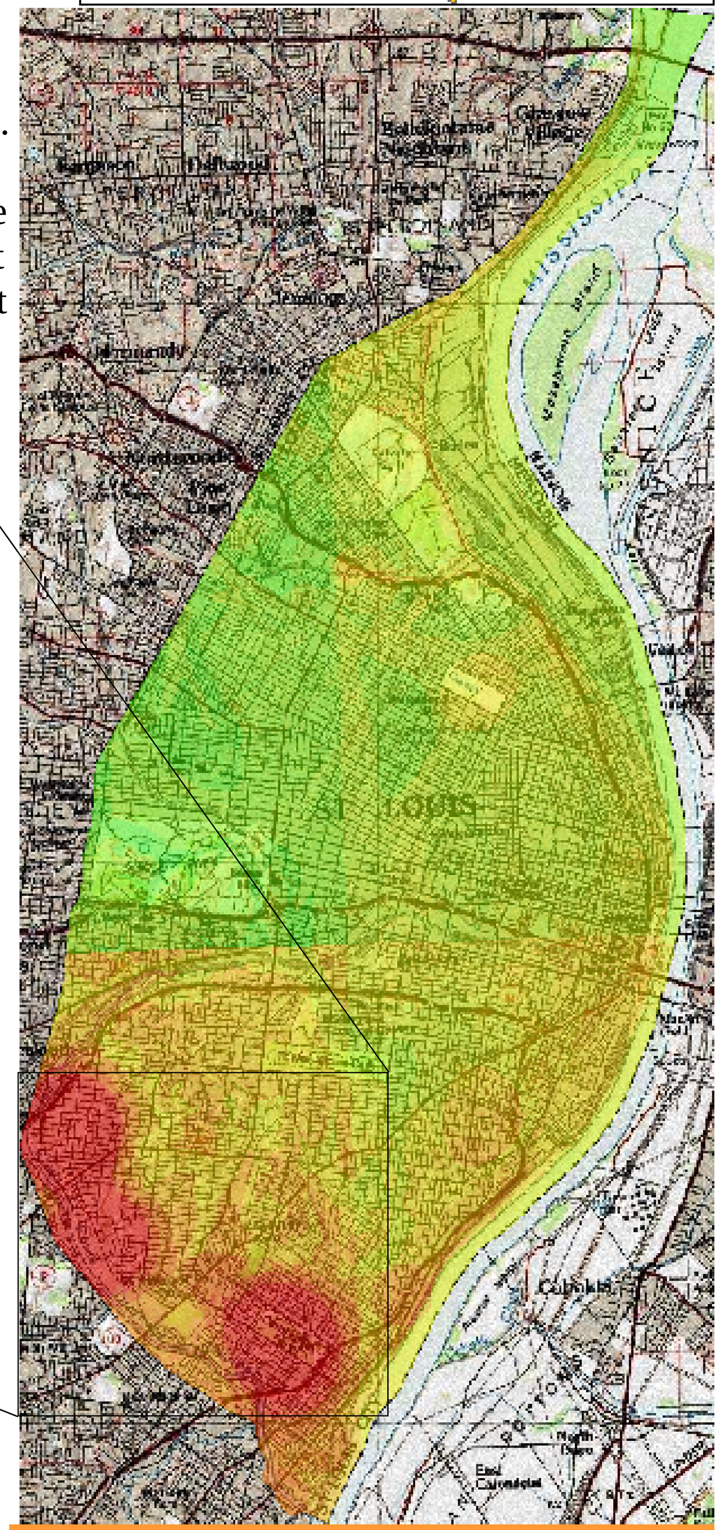
Combining the Risk Factors: Equal and Varying Weights

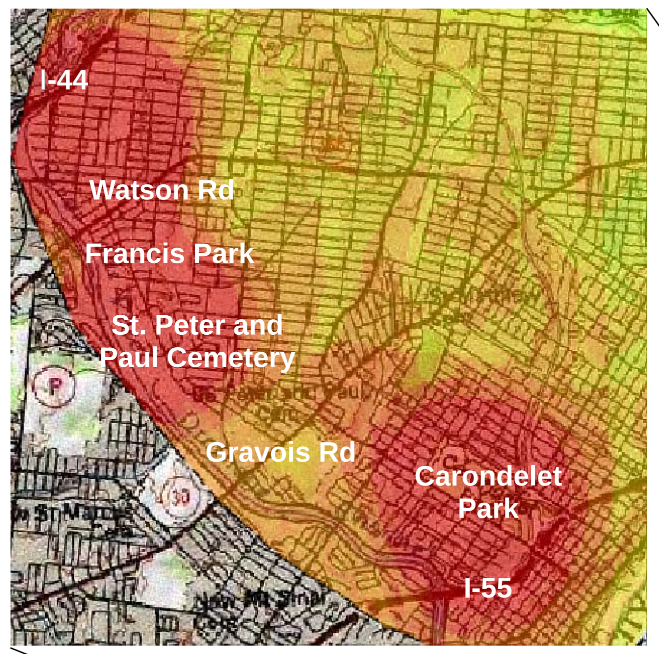
Once the 6 risk factors were individually reclassified, they were added together using the weighted sum tool in Spatial Analyst. This tool highlighted the areas in St. Louis that had the highest combined value of reclassified sinkhole risk factors. First, they were added with equal weights to see the distribution of the values. However, the more accurate analysis included varying the weights since different factors are more influential than others in contributing to sinkhole formation. Though the two results were slightly different, they both found three regions that had the highest concentrated risk.



Social Implications

When a USGS topographic map of St. Louis was overlain with the varying weights total risk map, the results indicate that the areas in St. Louis with the highest risk for sinkhole formation are Carondelet Park, Interstate 55, St. Peter and Paul Cemetery, Interstate 44, Francis Park, Gravois Road, and Watson Road.





Urban planners may have used this high sinkhole risk land appropriately. Parks and cemeteries do not have the same threat to humans as residential or commercial lots. However, there are major interstates and interchanges with high traffic counts sited over the highest risk areas. The areas identified by this risk analysis must be monitored closely over time to ensure that sudden sinkhole formation does not occur and that risk to human life and property are minimized.

Cartographer: Alissa Marturano
April 30, 2009
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Map Coordinate System and Projection: NAD_1983_UTM_Zone_15N/ Transverse Mercator

Data Source: Missouri Spatial Data Information Service http://msdis.missouri.edu/

References: [1]"Karst Area Potential Determinan Using GIS." 2008. University Science of Malaysia. http://karstaceh.com/entrance/ karst-area-potential-determinan-using-gis