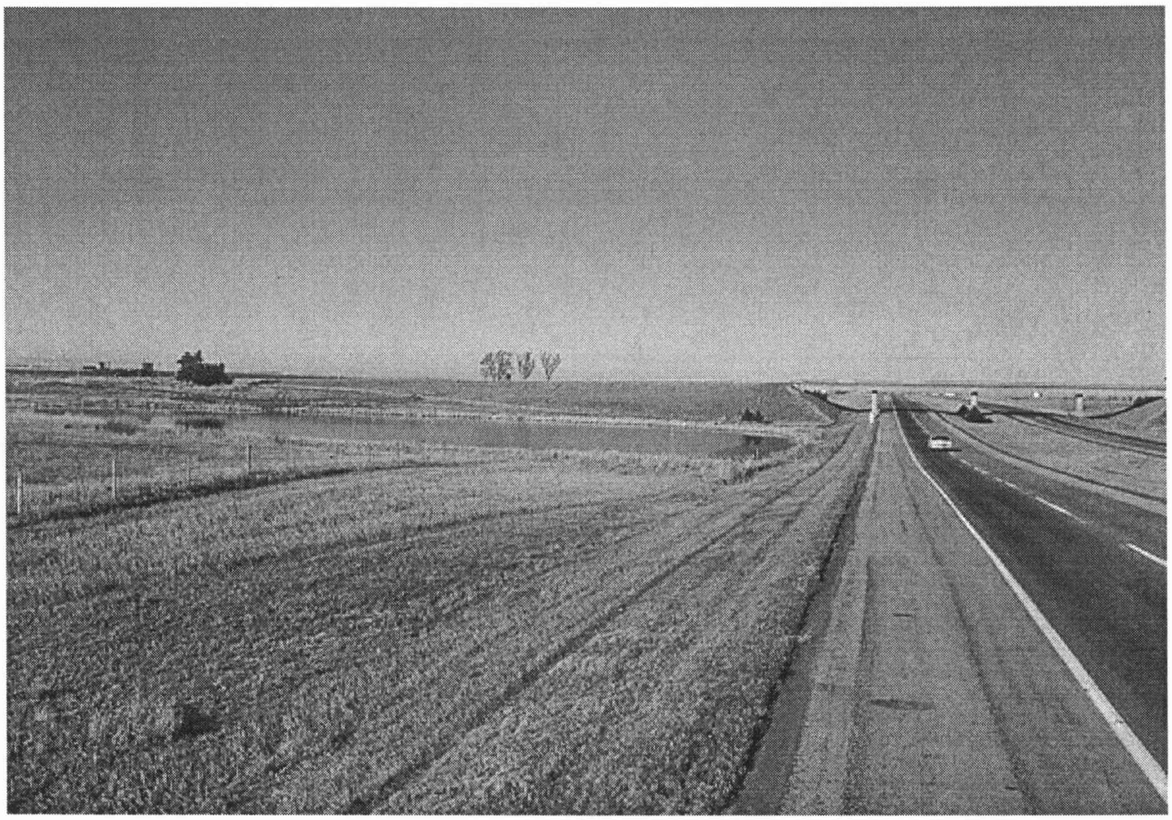
Kansas Geological Survey

The Need for a Geologic Hazards Program in Kansas

By

Gregory C. Ohlmacher



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Introduction

Geologic hazards have caused considerable property damage and loss of life in Kansas. For example since 1995, floods have damaged houses and businesses in Johnson, Wyandotte, Sedgwick, and other counties; land subsidence destroyed two medical buildings in Wyandotte County, and landslides have destroyed houses in Johnson County and closed roads in Riley and Ellis counties. Despite the need for information, very little has been done to systematically evaluate geologic hazards and generate maps defining the areas susceptible to these hazards.

Bates and Jackson (1987) define geologic hazard as "a naturally occurring or man-made geologic condition or phenomenon that presents a risk of potential danger to life and property." Geologic hazards include floods, wind erosion, earthquakes, landslides, expansive soils, land subsidence, streambank erosion, piping of soils, and hydrocompaction. This report covers the current state of knowledge on geologic hazards and makes recommendations for needed studies. It is intended to be a guide for developing a multiyear program to study and map geologic hazards. The end product would be a series of maps and reports serving as guides for government planners, city and county engineers, and persons or groups needing this information for planning purposes.

Public Safety

The primary reason the Kansas Geological Survey is interested in geologic hazards is to protect and improve public safety. People have been injured and some have died as a result of geologic hazards. Additionally, geologic hazards cause considerable property damage every year. Knowledge of the causes and distribution of geologic hazards could minimize property losses and personal injuries.

The Kansas Geological Survey strives to produce the most accurate and up-to-date geologic hazard maps and reports. The maps and reports that will be produced are intended for planning purposes only. They provide guides that local jurisdictions can use to designate areas that might need site-specific investigations by a geologist and civil engineer. Jurisdictions should require site-specific investigations prior to development in areas of recognized or suspected geologic hazards.

Home and building owners with property in a geologic hazard area should hire a geologist and civil engineer to investigate their site, to evaluate the extent of the hazard, and if necessary, to provide recommendations for possible remedial work.

Cover photograph: Active land subsidence along Interstate 70 in Russell County caused by dissolution of salt layers in bedrock. The lake marks the center of the sinkhole. The dip in Interstate 70 is visible. The bridge over Interstate 70 is also in the sinkhole. Photo by John Charlton, Kansas Geological Survey.

Natural Hazards

Natural hazards include geologic, meteorologic, marine, and coastal hazards. In Kansas natural hazards include tornadoes, straight winds, droughts, hail, blizzards, floods, subsidence, landslides, expansive soils, erosion, winter storms (snow and ice), fog, lightning, wildfires, and smoke from controlled burning. Other natural hazards could occur in the state, but are not covered in this document.

Natural Hazards Ratings

Natural hazards occur as events of one or more occurrences during a certain time frame. For example, a cold front may spawn several tornadoes. Each tornado is an occurrence, and all the tornadoes during the storm constitute a tornado event. When the Federal Emergency Management Agency (FEMA) considers damages, it is done on an event basis. The time frame for an event will vary depending on the type of hazard. A tornado event may last a day or two while a landslide event may include landslides that occurred over several months.

Table 1 lists and rates natural hazards to determine the relative level of risk. Three criteria are used to rate the risk: frequency, damage area, and distribution. Frequency is a measure of how often a hazard causes damage. Hazards that are common during certain seasons are labeled seasonal, while those that vary with climatic fluctuations (wet versus dry years) are labeled climatic in table 1. Damage area is used as a measure of the dollar damage caused by an event. A landslide event might involve acres to tens of acres and damage 1 to 20 structures, while a tornado event might involve hundreds of acres and damage 50-100 structures, and an earthquake might involve thousands of acres and damage 100's structures. The distribution is a measure of how much of the state is affected by the hazard and our ability to avoid the effects. Tornadoes occur statewide and the risk is relatively uniform throughout the state. Landslides are localized with some areas having a higher risk of landslides depending on slope, geologic materials, and moisture conditions.

A rating is determined for each hazard. Frequency and damage area are rated on a scale of 1 to 5 with 5 being most frequent or damaging the largest area. Statewide hazards are assigned 2 points and localized hazards 1 point. Thus the maximum risk value is 12 and the minimum value is 3. The highest risk rating of any natural hazard in Kansas is 10 points.

Other methods exist for evaluating the relative level of risk for natural and other hazards. These other methods will produce different results depending on the input used and the person or persons doing the evaluation.

Tornadoes are the highest-rated natural hazard in the state. On average Kansas has 47 tornadoes per year based on 45 years of data (National Climatic Data Center, 2000). These tornadoes occur in about 12 storms or tornado events per year. All of these have the potential of doing damage. The frequency is then set at monthly; tornadoes however are seasonal, occurring mostly in the spring and fall. A tornado can cut a path from meters to a kilometer wide through a city or town, so the damage area can be hundreds of acres. Tornadoes can occur anywhere in the state. Summing the values for frequency (4), damage area (4), and distribution (2), the risk rating for tornadoes is 10.

There were 55 damaging hailstorms from January 1998 to December 1999 (National Climatic Data Center, 2000). These hailstorms can be subdivided into seven events per year, with storms commonly occurring in the spring and summer. Thus, the frequency is bimonthly and seasonal. The damage area from hailstorms is large—in the hundreds of acres, and hailstorms can occur statewide. Summing the values for frequency (4), damage area (4), and distribution (2), the risk rating for hail is 10.

Table 1.—Natural Hazards Rating (Higher values equate to greater hazard).

Hazard	Frequency	Distribution	Damage Area	Rating
Tornado	Monthly (seasonal)	Statewide	Large	10
Hail	Bimonthly (seasonal)	Statewide	Large	10
Straight winds	Monthly	Statewide	Large	10
Droughts	Decades	Statewide	Very large	9
Wildfires	Monthly	Statewide	Moderate	9
Floods	Yearly (seasonal, climatic)	Localized	Large	8
Lightning	Weekly (seasonal)	Statewide	Very small	8
Wind Erosion	Decades	Localized	Very large	8
Earthquakes	Century	Localized	Very large	7
Landslides	Yearly (seasonal, climatic)	Localized	Moderate	7
Mine Subsidence	Yearly	Localized	Moderate	7
Expansive Soils	Yearly (climatic)	Localized	Moderate	7
Streambank Erosion	Decade?	Localized	Moderate?	6
Natural Subsidence	Decade	Localized	Small	5
Piping	No data	No data	No data	?
Hydrocompaction	No data	No data	No data	?

Frequency	Points	Extent	Points	Damage area	Size (acres)	Points
Weekly	5	Statewide	2	Very large	1,000+	5
Monthly	4	Localized	1	Large	100-1,000	4
Yearly	3			Moderate	10-100	3
Decade	2			Small	1-10	2
Century	1			Very Small	<1	1

Hazards not considered: blizzards, winter storms, and blasting

Straight winds are high-speed winds that are not associated with tornadoes or hurricanes. The National Climatic Data Center (2000) reports that there were six storms in 1998 that caused more that $1 million dollars in property damage and one storm in 1999 at that level. Thus, the frequency is between yearly and monthly. Some storms that caused wind damage in one town elsewhere could have spawned a tornado. The damage area from straight winds is large on the order of hundreds of acres. Straight winds are a statewide phenomena. Summing the frequency (4), damage area (4), and distribution (2), the risk rating for straight winds is 10.

The data on droughts is based on the information gathered on wind erosion. Droughts are climatic fluctuations, and the frequency is in decades. The damage area from droughts is very large, and droughts occur statewide. Summing the frequency (2), damage area (5), and distribution (2), the risk rating of droughts is 9.

Wildfires are caused by lightning and human factors (careless smoking, arson, intentional burning, etc.). On average 4272 wildfires occur in Kansas every year based on 14 years of data (Casey McCoy, Kansas Forestry Service, personal communication, 2000). Thus, the frequency is set at monthly. The damage area of these wildfires is moderate with about 30 acres damaged per wildfire. Wildfires occur statewide. Summing the frequency (4), damage area (3), and distribution (2), the risk rating of wildfires is 9.

The frequency of lightning is somewhere between weekly and monthly and commonly occurs in the spring, summer, and fall. The damage area from lightning is very small. It could be argued that lightning hitting the power grid causes personal property damage over a small to moderate-sized area. This would increase the risk rating of lightning strikes by one point, but not change position in table 1. Lightning occurs statewide. Summing the frequency (5), damage area (1), and distribution (2), the risk ranking of lightning is 8.

It is clear from the above discussion that the money spent on improving early warning for severe storms is justified. Tornadoes will continue to occur. Mitigation efforts should focus on early warning, providing safe rooms in houses and buildings (Federal Emergency Management Agency, 1998), and improved building design.

Geologic Hazards

Unlike meteorologic hazards that are widespread throughout the state, either the areas susceptible to geologic hazards can be avoided or construction methods exist that can minimize or eliminate the damages and injuries provided that the extent of the hazard is known. For example, all structures in Kansas have the potential for being damaged by tornadoes; however, many areas in the state are not susceptible to landslides. By avoiding areas with a high susceptibility to geologic hazards and using proper construction methods in areas with low to moderate susceptibility, the risks to people and properties can be minimized.

This section highlights the state of knowledge about the extent and degree of each geologic hazard and makes recommendations for future studies. Overall, systematic studies of geologic hazards in Kansas are lacking. The hazards studied in the greatest detail are floods, earthquakes, and land subsidence related to lead-zinc, salt, and coal mining. Flood-hazard maps are available for jurisdictions that are participating in the National Flood Insurance Program. Landslide investigations are in progress. Frequencies reported here are based on reported occurrences and are not statistically valid. Damage areas are based on known events, and distributions are based on the distribution of rock layers (geologic formations) associated with the hazard.

The needs for studies of geologic hazards are subdivided into five areas: (1) hazard mapping, (2) research, (3) prediction and real-time monitoring, (4) public awareness, and (5) mitigation and remediation. *Hazard mapping* is the delineation of the physical extent of the hazard and determination of the probability of occurrence. Four levels of maps can be produced. Inventory maps show the current extent of geologic hazards. Susceptibility maps depict the areas that may have problems in the future without reference to how often the geologic hazard occurs. Hazard maps show the probability of future problems within a given time frame (recurrence interval). Risk maps evaluate the physical and economic losses due to geologic-hazard event. The data needed to produce susceptibility maps are available. Hazard maps require data on frequency of occurrence that are not available and may not be easily obtained. Risk maps are based on hazard maps, land use, and economic data. At a minimum the Kansas Geological Survey should strive to produce inventory, susceptibility, and hazard maps where sufficient data are available.

Research into geologic hazards includes studies of the causal factors, probability of occurrence, frequency, triggering mechanisms, and other issues related to geologic hazards. Research overlaps with other need areas especially hazard mapping, prediction, and real-time monitoring.

Prediction and real-time monitoring includes the need for developing warning systems to protect health and safety of our citizens, critical facilities, structures, and general infrastructure of the state. Inventory and susceptibility maps are used to identify critical structures that need real-time monitoring. Research is needed to determine the best methods for real-time monitoring of geologic hazards.

Public awareness takes many forms. All geologic hazards with the exception of piping and hydrocompaction need Kansas Geological Survey (KGS) Public Information Circulars that explain the general nature of the hazard. As hazard mapping progresses, Homebuyer's Guides should be developed to answer more specific questions related to purchasing and maintaining a house. Hazard maps should be readily available to the public. One way of accomplishing this is having the maps accessible on the Kansas Geological Survey web site. Public meetings and field trips provide a method of educating local officials and the general public about geologic hazards. Local officials and policy-makers need to be educated in the potential uses of the data produced.

Mitigation strategies and remedial measures need to be developed for all geologic hazards in order to see actual reductions in losses and an increase in public safety. The development of mitigation strategies and remedial measures will require a cooperative effort of both public and private organizations and involves areas of expertise not currently available at the Kansas Geological Survey.

Floods

Three declared national disasters between 1990 and 1999 highlight the importance of flooding in the state. Floods occur when the discharge (volume of water per unit time) exceeds the carrying capacity of the channel and the water spills out of the channel onto the floodplain. Floods in Kansas are associated with severe or prolonged rainstorms and occasionally by snowmelt and ice jams. Dam and levee failures have caused floods in the state. Additionally, fluctuations in water levels of lakes can damage property that was built too close to the shore. Although one of the preceding triggers is needed to initiate a flood, other factors, including the surface geometry of the drainage basin, the distribution and properties of the surficial materials (soil and rock), and land usage, also affect the discharge at a point along the flood path.

Examples of flood damages in the state are listed in table 2. Three floods along the Kansas River caused major damage during the 20th century. Damage estimates for the 1935 flood are not available; however, a detailed list of damages in Follansbee and Spiegel (1937) indicates that this was a very costly flood. Smaller streams are also subject to repeated flooding. Turkey Creek in Johnson and Wyandotte counties has flooded 7 times in 25 years damaging homes and businesses. Table 2 also highlights that floods often claim lives.

Table 2—Examples of flood damages for 1935-1998.
Damages are in millions of dollars and are not adjusted for inflation.

Year	Location	Deaths	Damages
1935	Republican and upper Kansas rivers	10	?
1951	Kansas, Missouri, Neosho, Verdigris, and Arkansas rivers	15	$758
1965	Arkansas River	3	$25
1976	Verdigris River	1	$20
1977	Kansas City area	6	$24
1979	Location not provided in data source	0	$27
1981	Great Bend area	0	$42
1982	Kansas City area	0	$20
1983	Location not provided in data source	0	$8
1984	Kansas City area	0	$78
1985	Location not provided in data source	0	$16
1986	Southeast Kansas	2	$132
1993a	Republican, Kansas, Missouri, and Marais des Cygnes rivers	0	$475+
1993b	Arkansas River and tributaries	2	$7
1998a	Kansas City area (10/4)	2	$13
1998b	Lower Arkansas River (11/1)	1	$55
1999	Northeast Kansas (6/27-28)	0	$2

Floods can occur along any stream in the state. Areas of higher ground around the floodplain provide safe areas during floods. Thus, the distribution of floods is localized. The damaging floods listed in table 2 are concentrated in more developed areas like Wichita and Kansas City. A flood can damage a wide area along the floodplain, and floods commonly damage thousands of acres. Flood-control works including dams, levees, and channelization have shown mixed results. While locally they have decreased the flood damage, these structural solutions change the dynamics of the stream and may promote flooding in other areas. Levees and channelization reduce the efficiency of the floodplain to mitigate flood effects and increase flooding both upstream and downstream of the structures.

Every year Kansas can expect at least one damaging flood. The National Climatic Data Center (2000) reported 52 floods that caused at least $1,000 in property damage in 1998 and 1999. These 52 floods were caused by 15 separate storms. Three of these storm events caused over a million dollars damage. Major storms that cause more than 10 million dollars damage appear to occur on average every other year between 1980 and 1999 (table 2).

The risk rating for floods is based on a yearly to biyearly frequency (3), localized distribution (1), and large damage area (4) that results in a risk rating of 8.

Flood hazard needs:

Hazard mapping: Federally subsidized flood insurance is available through FEMA to jurisdictions in the state that have chosen to participate in the program. Those jurisdictions now have flood-hazard maps. However, many of these maps need updating because urbanization and modifications of stream channels have changed the dynamics of the stream. There is a need for flood-hazard maps in areas not covered by FEMA Flood Insurance Rate Maps and for updating current flood-hazard maps.

Research: Research is needed into the effects of climate change and land-use patterns on flood-frequency predictions. Gosnold et al. (2000) highlight the need for reevaluating flood prediction by including climate-change factors and changing land-use patterns.

Research directed toward determining the effect urbanization on flood-mitigation strategies for Kansas is needed. The stream channel and floodplain provide natural areas for water storage during a flood (Rosgen, 1996). The floodplain, for example, allows the water to spread out, slow down, and infiltrate into the alluvium. By leaving areas with high infiltration rates undeveloped, these areas could retain water during a flood and reduce the severity.

Prediction and monitoring: The National Weather Service currently issues flood warnings based on meteorological conditions. Real-time monitoring is accomplished through the U. S. Geological Survey (USGS), which operates stream-gauging stations throughout Kansas. Additionally, local jurisdictions in the Kansas City metropolitan area operate several stream-gauging stations as part of their flood-warning and response systems. Additional gauging stations are needed in Kansas.

Public Outreach: General information of floods is available through FEMA, the flood-insurance program, and the USGS.

Mitigation and remediation: Mitigation strategies have been established for floods in Kansas. Primarily, the mitigation strategies used include acquisitions of property in flood-prone areas, elevating structures above flood levels, and protecting critical facilities.

Wind erosion

Wind erosion or deflation occurs in areas of sparse vegetation when the soil loses moisture. As soil moisture decreases the cohesion between the mineral grains also decreases, and winds can then remove the silt- and sand-sized particles. Wind erosion produces a shallow basin (depression) called a deflation basin or blow out. Wind erosion increases during prolonged droughts such as occurred during the Dust Bowl era.

The degree to which an area is susceptible to wind erosion varies throughout the state. The semi-arid areas in the west are more susceptible than the eastern portion of the state (Leighton, 1938). The damage area for wind erosion is very large. The Dust Bowl era (1934-37) had 21.5 million acres in Kansas damaged by wind erosion (Throckmorton and Compton, 1938). The drought of 1975-76 saw 891,000 acres damaged in the state (Jacobberger, 1982).

Reports indicate that four major droughts with wind erosion have occurred in Kansas: 1890-94, 1910-14, 1934-37, and 1975-76 (Throckmorton and Compton, 1938, Jacobberger, 1982). A fifth drought occurred in 1952-53 (Taylor, 1954); however, no reports of wind damage were located. The dates from this limited data set indicate a 20-30 year recurrence interval for droughts with wind erosion.

Leighton (1938) presented some geologic factors associated with wind erosion. Wind erosion is more common in loess, dunes, and unconsolidated Tertiary sediments of western Kansas. The Kansas Geological Survey published a generalized map showing the distribution of loess in the state (Welch and Hale, 1988). The Permian red beds of south-central Kansas also may be subject to wind erosion. Leighton pointed out that the windward side of the hill and hillcrest areas are more susceptible to wind erosion.

The risk rating for wind erosion is based on a frequency in decades (2), localized distribution (1), and very large damage area (5) that results in a risk rating of 8.

Wind-erosion hazard needs:

Traditionally, the U. S. Department of Agriculture and Kansas State University Research and Extension have been responsible for studies of wind erosion. However, opportunities exist for collaborative research by the Kansas Geological Survey and those organizations.

Research: Research needs include studies and hazard mapping of rock and soil units susceptible to wind erosion. Wind erosion is associated with silty and fine sandy soils like loess. Combining the local geologic materials with the soil units and the local topography may help delineate areas of potential wind erosion.

Earthquakes

Twenty-five earthquakes were reported in the state between 1867 and 1976 (DuBois and Wilson, 1978). The largest had a Modified Mercalli (MM) intensity of VII, and occurred near Wamego, Pottawatomie County, in 1867. The MM intensity scale measures the effects of an earthquake on people and buildings. For the 1867 earthquake, blocks fell from buildings, objects were knocked off shelves, and dishes and windows were broken. Ground surface rupture and waterspouts were reported near Wamego. This earthquake would have a Richter magnitude between 5.0 and 5.5. Studies of earthquakes in Kansas indicate that a magnitude 6 earthquake can be expected once every 2,000 years (Steeples et al., 1990).

Earthquakes can occur anywhere in the state with northeastern Kansas having a higher probability of damaging earthquakes (fig. 1). The damage area for an earthquake event is very large. The area with the heaviest damage from the 1867 earthquake extended from Leavenworth to Salina (DuBois and Wilson, 1978). Thus, the damage area was approximately 2,000 square miles or 1.28 million acres. Today, a similar earthquake would damage Kansas City, Lawrence, Topeka, Manhattan, Junction City, Abilene, and the cities mentioned above.

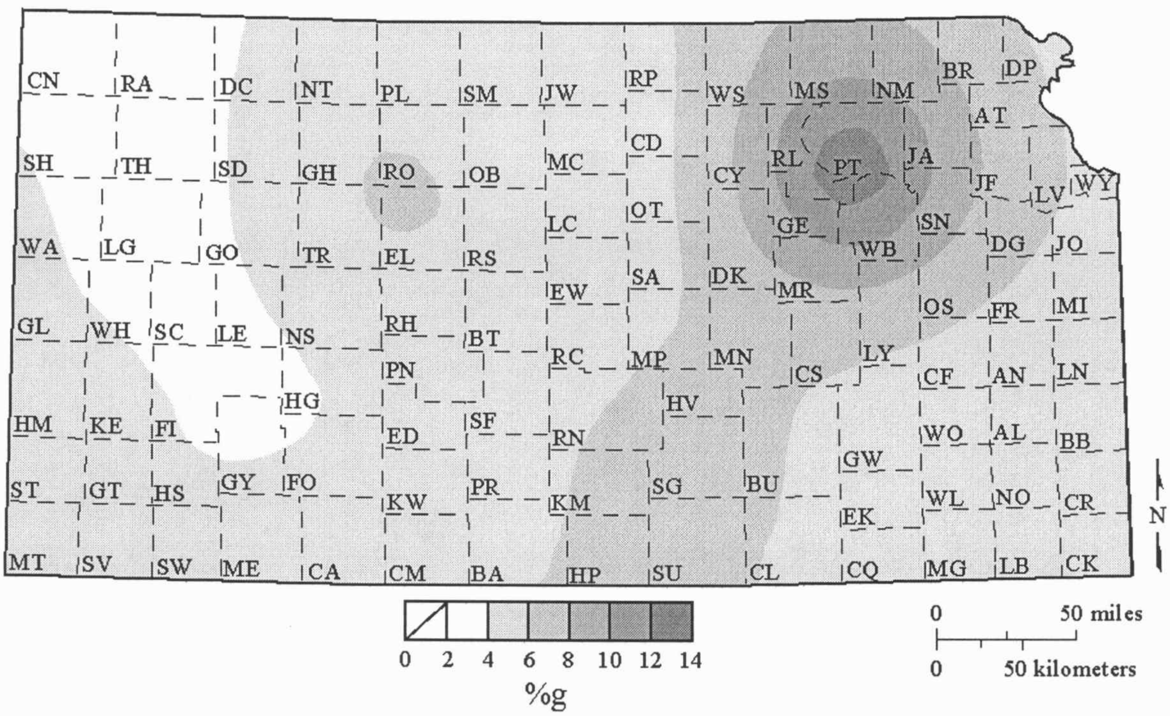

Figure 1.—Map showing the seismic hazard for Kansas. This map depicts the peak acceleration that would occur during an earthquake that has a 2% probability of occurring during a 50-year interval. Peak acceleration is given as a percentage of gravity (%g).

The frequency of damaging earthquakes is very low. This does not mean that we can ignore earthquakes. Improving building designs, retrofitting existing structures, and better siting of structures can reduce earthquake damage.

The risk rating for earthquakes is based on a frequency in thousands of years (1), localized distribution (1), and very large damage area (5) that results in a risk rating of 7.

Earthquake hazard needs:

Hazard mapping: Seismic-hazard mapping should concentrate on soil and rock response during an earthquake. Areas of primary interest are those that can undergo liquefaction, landsliding, and materials that magnify vibrations.

Research: The primary problem for understanding the earthquake hazards is the extremely limited historical database. The oldest and largest earthquake in Kansas is the 1867 event. Because the Kansas seismic network only operated for 12 years, the database of microseismicity used to determine earthquake probability is very small. This highlights the importance of paleoseismology studies. Paleoseismology is the study of prehistoric earthquakes (paleoearthquakes). Paleoseismology studies include mapping liquefaction features along streams and rivers, searching for fault displacement in Quaternary deposits, and searching for earthquake-related landforms. Liquefaction features were investigated along the Kansas River near Wamego (Niemi et al., 1998), but conclusive evidence for paleoearthquakes could not be found. Ohlmacher and Berendsen are investigating stream deposits in the Manhattan 1° x 2° quadrangle. This work should be expanded to include streams and rivers throughout the state.

Research into the structural and tectonic setting of Kansas also is needed. Numerous faults are mapped in Kansas. The recommended research involves detailed mapping and examining these faults for paleoearthquakes and the potential future earthquake activity. By placing these faults into the current tectonic setting and stresses of the Midwest, it may be possible to determine the potential for these faults to produce earthquakes.

Prediction and monitoring: Monitoring of earthquakes needs to be improved in the state by increasing the number of seismographs. Only one seismograph exists on the USGS seismic network in the state, and that seismograph is in western Kansas. The 1999 mine subsidence/earthquake in Kansas City, Kansas, highlights the need for seismographs in eastern Kansas. The closest seismograph to Kansas City is more than 200 miles away, and yet the area with the greatest risk is just west of Kansas City (Figure 1).

Public Outreach: The Kansas Geological Survey has published a Public Information Circular on earthquakes (Steeples and Brosius, 1996). The need for further public outreach will be based on the results of earthquake research.

Landslides

Landslides are downslope movements of soil and rock (fig. 2). In general the causes of landslides are susceptible soils and rock, steep slopes, and high soil moisture. Kansas is not immune to damaging landslides. Table 3 contains examples of damaging landslides that occurred from 1990 to 1999. The costs presented in table 3 are incomplete. For example the estimate for the Overland Park landslide is based on the values of the houses ($500,000 and $400,000), plus a report that one of the homeowners lost $250,000 in personal property that was destroyed with the house. This estimate does not include the costs of post-landslide studies, removal of the damaged houses, repair of the slope, remediation measures done to protect neighboring properties, and lawsuits by homeowners and owners of adjacent properties.

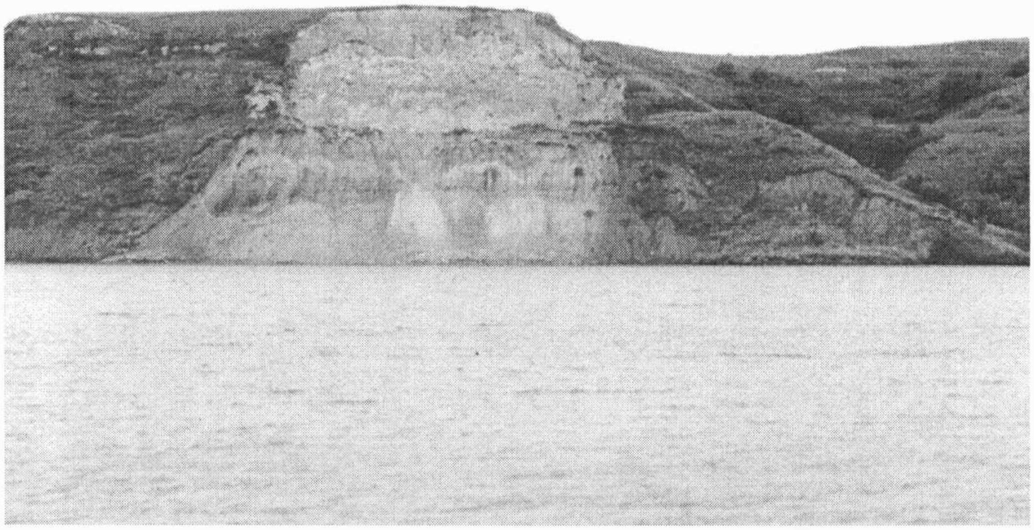

Figure 2.—Landslide that occurred in 1999 at Clark County Fishing Lake. The local relief is about 170 feet. The landslide extends from the hilltop to below the lake surface.

Table 3.—Examples of landslide damage 1990-99. Costs are in millions of dollars.

Year	Location	Damages	Costs
1990	Leawood	Landslide damages backyard and decks of two houses	$0.12+
1994	Leavenworth	Two landslides develop in city park	$0.31
1995	Atchison	Landslide damaged Riverview Drive. Landslide had been active since 1959	
1995	Overland Park	Landslide damages two houses destroyed and four other lots damaged	$1.15+
1995	Manhattan	Landslide closes McDowell Creek Road	$0.88
1995	Hays-Saline River	Numerous landslides; one blocked US Highway 183	
1995?	Atchison	Landslide damaged side yard of house	
1997	Leavenworth	Landslides slow construction on highway	
1997	Atchison	Landslide damaged forced main. Same as 1995 Riverview Drive landslide discussed above	
1998	Stanley	Landslide damages one house and backyard of a second	$0.36+
1998	Douglas County	Landslide closed road and beach at Lone Star Lake	$0.17
1998-1999	Lawrence	Two landslides damage concrete channel and block drainage ditch	
1999	Kansas City	Landslide damaged backyard of daycare facility	

One could argue that the Overland Park landslide destroyed very expensive houses. It also damaged four undeveloped lots. If the same-sized landslide hit a fully developed slope with six $150,000 houses, landslide damages would still be over $900,000.

Unlike tornado and hail damage, landslide damage is not covered by most homeowner insurance policies. With a tornado, the damage is regional and thus the insurance industry can spread the costs to homeowners throughout the state. Landslides are localized problems. Many homeowners don't need landslide insurance, and thus insurance companies cannot spread the costs over a large number of homeowners.

The landslide overview map of the United States (Radbruch-Hall et al., 1982) presents what is currently known about the extent of the landslide hazard in Kansas. The map (fig. 3) shows one small area with moderate incidence in northwest Marion County and one small area with high susceptibility to landslides in northwest Hamilton County. Several areas of Kansas are shown that have moderate susceptibility including the Smoky Hills (from Washington and Republic counties to Hodgeman and Ford counties), northeast Kansas, southern Chautauqua County, and northwest Cheyenne County. While the landslide overview map of the United States provides some insight into the extent of the landslide problems in Kansas, it is not a systematic map that can be used by local planners and engineers for planning and permitting purposes.

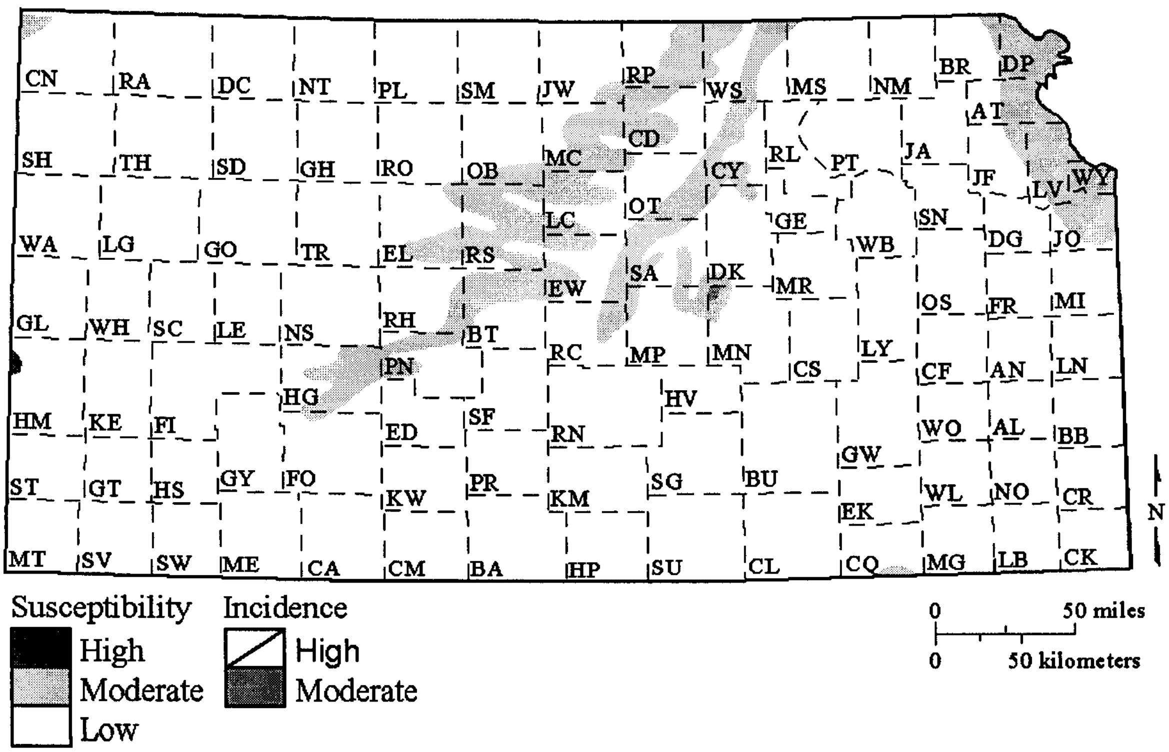

Figure 3.— Kansas portion of the Landslide Overview Map of the United States (Radbruch-Hall et al., 1982). Moderate-hazard levels indicate that 1.5% to 15% of the area is either susceptible to landslides or is landsliding.

Ellsworth, Russell, and Ellis counties have numerous examples of recent landslides. Portions of these counties may reach or exceed the USGS's criteria for high incidence of landslides, which require that greater than 15% of an area be involved in landsliding. This could be proven by systematically mapping the landslides. Damaging landslides occur in developed areas, especially the Kansas City metropolitan area. Here, the incidence of landslides is low to moderate, but the amount of development places more structures at risk.

Only two areas of the state have been systematically mapped for landslides. The western edges of Morton, Stanton, and Hamilton counties were mapped at 1:250,000 scale (1 inch = 3.95 miles) by Colton et al. (1975), and the City of Atchison was published at 1:36,000 scale (1 inch = 0.57 miles) by Ohlmacher (2000). The mapping by Colton et al. (1975) was part of landslide mapping in Colorado by the USGS and shows no landslides in Kansas large enough to map at 1:250,000 scale. The landslide mapping in Atchison was a pilot project by the Kansas Geological Survey to develop a landslide-hazard-mapping program and to demonstrate the types of products that can be produced. Currently, landslide mapping is continuing in Leavenworth County.

The damage area for an individual landslide varies from tenths of acres to hundreds of acres. However, landslides often occur as landslide events, for example the landslides of 1995 (table 3). Insufficient data exist to determine the number of damaging landslides an urban area could expect during a landslide event. The damage area from a landslide event could be very large. Hundreds of acres were damaged in the Smoky Hills during the 1995 event. No cities are located in the landslide-prone area of the Smoky Hills; however, hillside development is occurring around some reservoirs. With slopes for "view lots" and the presence of susceptible rock units around some reservoirs, landslides pose a real risk for vacation homes.

Because historical data on landslides have not been collected and organized, the frequency of landslide events is speculative. According to the data in table 3, at least one damaging landslide occurs every other year in Kansas. Additionally, the number of landslides may vary with climatic cycles. Wet years have more landslides and a greater risk of a damaging landslide. The Kansas Department of Transportation and local highway-maintenance departments repair landslide damage every year. Thus the actual frequency of damaging landslides is yearly to quarterly.

The risk rating for landslides is based on a yearly frequency (3), localized distribution (1), and moderate damage area (3) that results in a risk rating of 7.

Landslide-hazard needs:

Hazard mapping: Landslide-inventory and susceptibility maps at about 1:36,000 scale need to be developed for the Kansas City metropolitan area and other urban areas with landslide concerns. Landslide-inventory and susceptibility maps at 1:100,000 scale are needed for most counties in Kansas. The county maps could be used to define further areas for detailed landslide-hazard maps. Landslide-inventory and susceptibility maps are needed for high-density recreational areas—i.e. Clinton, Perry, Wilson, and other reservoirs in Kansas. In areas with the greatest risk, landslide-hazard maps including probability of failure could be developed.

Research: Research into the causal factors of landslides is needed. Variations in the local geology and slope morphology affect the density and types of landslides observed. This research will be conducted along with inventory mapping and is required to produce quality landslide-susceptibility maps.

Research is needed in determining the probability of landslide occurrence. This could take many forms: collection and tabulation of historical landslide reports, research into triggering mechanisms, and dendrochronology studies in areas of older landslide deposits. Reports of historical landslides are found in a variety of sources including the Kansas Department of Transportation, local newspapers, city and county offices, and city and county historical societies.

Research on the mechanics and triggering conditions of landslides will improve our predictive capability. For example, extended wet periods probably have a greater effect on triggering landslides than individual storms. A soil-instrumentation program that examines moisture variations and precipitation over 5 to 10 years may aid in developing a landslide-warning system for landslide prone areas.

Prediction and monitoring: The research into triggering mechanisms may reveal combinations of antecedent moisture and precipitation that initiate landslides. This can then be used to predict periods of potential-landslide activity based on weather reports. Hazard mapping may reveal critical facilities and infrastructure that may need real-time monitoring.

Public outreach: A KGS Public Information Circular is already available for landslides (Ohlmacher, 1999). The need exists for a homebuyer's guide for the Kansas City metropolitan area. As hazard maps become available, they should be posted on the Kansas Geological Survey web site.

Land subsidence

Land subsidence is the lowering of the ground-surface elevation caused by (1) the collapse of an underground void, (2) the extraction of subsurface fluids, or (3) the removal of fines by ground-water flow (piping). Shrinking of expansive soils also will cause land subsidence or settlement. Expansive soils and piping are covered separately in this report. The surface manifestation of land subsidence is a depression called a sinkhole (fig. 4). The sources of natural land subsidence in Kansas include dissolution of limestone, gypsum, and rock salt by ground-water flow. Ground-water flow opens up caves in these rock units that can collapse.

Man-influenced subsidence includes collapses over underground coal, salt, limestone, and lead-zinc mines along with salt dissolution associated with oil wells. The salt dissolution associated with oil wells seams to result from the pumping of oil-field brine down old oil wells and by ground-water flow along an improperly sealed well casing. Brine is a byproduct from the extraction of oil. Because brine is corrosive, it eats the casing of the old oil wells and leaks into bedrock. In layers of rock salt, the brine dissolves the salt, creating a cavity that can collapse and cause land subsidence.

Examples of salt dissolution associated with oil wells are the active sinkholes along Interstate 70 in Russell County (see cover photograph).

Figure 4.—Sinkhole that opened in pasture land near Ashland in May 2000. The central collapsed area is about 30 m (100 ft) in diameter and about 25 m (50 ft) deep. The outer edge of the sinkhole is at the rise where the pickup is parked.

Extraction of fluids from the ground also can lead to land subsidence. The removal of fluid causes a pressure drop in the remaining fluid and the thickness of the geologic unit containing the fluid decreases. The two primary fluids being pumped in Kansas are oil and ground water. No reports currently exist on land subsidence associated with fluid extraction. That is not to say that land subsidence associated with these practices does not exist. Studies of land subsidence resulting from extraction of ground water are more important because some aquifers are composed of poorly consolidated sands, silts, and clays.

Table 4 lists examples of land subsidence in the state. McCauley et al. (1983) reported nearly 910 mine hazards associated with underground lead-zinc mines in southeast Kansas. These mine hazards included 307 mine collapses and 589 hazardous mine shafts.

Two examples of damaging sinkholes are the 1965-66 and the 1998-99 subsidence events of Wyandotte County. The 1965-66 event damaged roads and destroyed houses. One house fell completely into a sinkhole. In the 1998-99 event, two medical buildings were destroyed by several sinkholes opening over a 6-month period. The collapse associated with the March 1999 sinkhole may have generated a magnitude 3.0 earthquake (James Lawson, personal communication, 1999). Both the 1965-66 and the 1998-99 events involved the collapse of abandoned underground limestone mines.

Table 4.—Examples of land subsidence.

Year	County (City)	Source	Size (acres)	Notes
1879	Meade	Salt solution	0.7	Destroyed wagon road Area of disturbance = 3.6 acres
1905	Cherokee (2)	Limestone solution	0.2	
1914	Reno (Hutchinson)	Salt mining	0.4	Parts of salt-processing plant
1924	Cherokee	Limestone solution	0.2	
1925	Reno (Hutchinson)	Salt mining	6.5	Downtown buildings damaged
1926	Wallace	Limestone solution	1.6	
1927	Mitchell	Limestone solution	1.1	This may be a piping failure
1929	Hamilton	Salt solution	0.2	
1937	Butler	Limestone solution	0.3	
1952	Reno (Hutchinson)	Salt mining	?	
1957	Russell (2)	Salt (oil well)	18.0 6.5	Both damaged I-70 Both still are actively sinking $1 million spent on repairs
1959	Barton	Salt (oil well)	1.6	
1964	Rice	Salt (oil well)	5.5	
1965	Wyandotte	Limestone mine		
1966	Wyandotte (numerous)	Limestone mine		Many houses destroyed and damaged
1974	Reno (Hutchinson)	Salt mining	1.6	Railroad damaged
1978	Reno (Hutchinson) (2)	Salt mining	0.3 1.2	
1981	Cherokee (2)	Lead-zinc mining	?	Damaged city streets
1982	Russell	Salt (oil well)	6.5	
1988	Stafford	Salt (oil well)	1.2	
1990	Wyandotte	Limestone mine	1.5	Damaged detached structure of a home
1998	Wyandotte	Limestone mine	~2.0	Damaged medical building
1999	Wyandotte	Limestone mine	3.8	Damaged medical building
2000	Wyandotte	Limestone mine	1.0	Damaged roads

Land subsidence associated with underground coal mining has damaged structures in the state. Areas with sinkholes caused by underground coal mining were mapped in the Cherry Creek basin (Kenny and McCauley, 1983). The Surface Mining Section of the Kansas Department of Health and Environment annually receives about 100 reports of land subsidence related to coal mining (Murray Balk, personal communication, 2000). Half of those inquiries require some type of remedial work. The Surface Mining Section pays hundreds of thousands of dollars per year for remedial measures related to land subsidence related to coal mining.

Land subsidence with natural causes exists in portions of the state where caves have formed in limestone, salt, and gypsum. An area of land subsidence exists in Sumner, Sedgwick, Reno, and McPherson counties where a thick Permian salt horizon is near the surface and fresh ground water can infiltrate the layer. In south-central Kansas, dissolution of Permian gypsum beds leads to caves and land subsidence (fig. 4). Land subsidence associated with collapse of caves in limestone has occurred in the eastern and central portions of Kansas (Merriam and Mann, 1957; Aber, 1992).

Land-subsidence problems appear to be widespread throughout the state (table 4); however, the susceptibility to land subsidence varies. For example, a zone including Sumner, Sedgwick, Reno, and McPherson counties is more susceptible to natural land subsidence from dissolution of salt. The sinkholes in table 4 are small (0-18 acres). If the five-acre 1998-99 event in Wyandotte County had occurred in a residential neighborhood, it could have destroyed 20 houses at say $150,000 per house and would have caused at least $3.0 million in damages.

The frequency of land-subsidence events is speculative. At least one damaging subsidence event occurred in each decade of the 20th century with the exception of 1940-49. Remember that no coal-mine subsidence events show up in table 4. Based on table 4, it would be safe to assume that at least one damaging sinkhole occurs every 10 years. This estimate may be far too low. The data for lead-zinc mining include 307 mine collapses since the beginning of mining in 1870 (McCauley et al., 1983). The average number of mine collapses would be at least two to three per year. Damaging sinkholes from underground coal mining occur every year.

The risk rating for land subsidence related to underground mining is based on a yearly frequency (3), localized distribution (1), and moderate damage area (3) that results in a risk rating of 7. The risk rating for land subsidence due to natural causes is based on a frequency in decades (2), localized distribution (1), and a small damage area (2) that results in a risk rating of 5.

Land-subsidence hazard needs:

Hazard mapping: Mapping is needed to define areas that are susceptible to land subsidence. These areas include karst areas such as those with limestone, gypsum, and salt dissolution; areas with underground mining; areas of dissolution mining of salt; and areas where salt beds are transected by oil wells. This would include a study of which geologic units are most susceptible to land subsidence. One or more pilot projects would assist in developing land-subsidence hazard mapping.

An inventory of existing information on underground mines in Kansas and an estimate of potential problem areas are needed. The database would include maps of the mined-out areas of the Weir-Pittsburg coal (Abernathy, 1944), maps of underground coal mining stored at the Kansas Geological Survey (Larry Brady, personal communication, 2000), and recently acquired underground-mine maps for active limestone, salt, and gypsum mines in Kansas. It should be highlighted that many older underground mines have no records.

Research: Research is needed into the potential for land subsidence associated with extraction of ground water and petroleum. Additionally, research is needed into the triggering mechanisms for natural land subsidence.

Research is needed into new tools for monitoring land subsidence. Radar interferometry is used to monitor displacements related to earthquakes and landslides. It may offer a method of monitoring land subsidence in western Kansas. However, the spatial resolution of satellite radar may not be adequate because the sinkholes are too small.

A study is needed on land-subsidence problems associated with coal mining. The Surface Mining Section of the Kansas Department of Health and Environment has data on sinkholes associated with underground coal mining.

Prediction and monitoring: The Kansas Department of Transportation is monitoring the sinkholes along Interstate 70 in Russell County. Land-subsidence hazard mapping may reveal other critical facilities and infrastructure that require real-time monitoring.

Public Outreach: The need exists for one or more KGS Public Information Circulars on land subsidence. Homebuyer's guides are needed in areas with natural and anthropogenic land subsidence.

Damage due to expansive soils

Expansive (swelling) soil contains clay minerals that increase in volume with increasing moisture content and decrease in volume as the soil dries. This expansion and contraction can damage highways and buildings. Common building damages include center lift, end lift, and basement-wall damage. Center lift occurs where the soils along the outside edge of the foundation shrink, lowering the outer walls of the building while the soils in the center remain wet so the center of the building remains high. In 1995, a house in Overland Park suffered damage by center lift, which forced the furnace through the basement ceiling (Meyer, 1995). End lift is the opposite effect where the soils were dry when the building was constructed and moisture was added to the outside lifting the outer walls. Basement damage involves expansion of soils outside the house forcing the walls into the basement. These damages are more severe where poor drainage exists around the foundation of the building.

All three types of damage due to expansive soils occur in Kansas. The semi-arid western portion of the state features dry soils that become wet when grass is planted and watered around the foundation leading to end-lift problems. In the more humid eastern portion of the state, the soils are wet especially in the spring and dry as summer progresses leading to center lift problems. A drought in eastern Kansas might lead to major damages from expansive soils as occurred in 1952-53 (Taylor, 1954).

Nationally, expansive soils cause $6 billion in damages per year (National Research Council, 1985). Taylor (1954) reported that the drought of 1952-53 damaged 65% of the homes in the Kansas City metropolitan area (both Kansas and Missouri) and caused an estimated 30 to 40 million dollars in damages. Every year streets and parking lots throughout the state are damaged because of expansive soils.

No systematic studies of expansive soils exist in Kansas. Data on expansive properties of agricultural soil units can be found in the National Resource Conservation Service (NRCS) County Soils Reports. At least one county engineer uses the NRCS soil maps to identify potential problem areas. Shales that contain high concentrations of clay are likely candidates for expansive clay minerals. Expansive clay minerals were identified in shale samples from the Pennsylvanian rocks in eastern Kansas. As shale weathers (breaks down), the expansive clays become part of the soil. Additionally, volcanic-ash deposits exist in many areas of central and western Kansas that weather into expansive soils.

Expansive-soil problems exist in most areas of the state. The size of the damage area for an expansive-soil event is hard to determine. Unlike a flood where the event is over in a few days, expansive-soil problems probably occur year round. The damage may be gradual or abrupt, and the damage may appear to be randomly distributed throughout the area instead of localized in one part of town. The 1952-53 expansive-soil event in Kansas City (Taylor, 1954) indicates a large area of damage. However, the yearly damage area would be moderate.

The frequency of problems also is highly speculative. Almost every year buildings and roads become damaged to the point that they need repair or replacement. It may even be that at least one structure a month reaches this point. However, events where many buildings and roads are damaged are less frequent and may be associated with climatic fluctuations. Thus, the frequency is set in years.

The risk rating for damage from expansive soils is based on a yearly frequency (3), localized distribution (1), and moderate damage area (3) that results in a risk ranking of 7.

A related problem is the expansion of shale by sulfide alteration. As pyrite in the shale weathers, it releases sulfate (SO_4) ions into the ground water. The sulfate ions combine with calcium in the ground water to form gypsum. There is an overall volume increase in the process of converting pyrite to gypsum, and the shale expands. Sulfide alteration has been reported in shale floors of underground limestone mines around Kansas City (Coveney and Parizek, 1977). However, several other processes occur in the same mines, including the removal of the limestone that allows the shale in the floor to expand, the shale is squeezed from below the mine pillars, and expansive clays are reported in the shales (Coveney and Parizek, 1977). Thus, the amount of damage attributed to sulfide alteration remains unknown.

Expansive-soil hazard needs:

Hazard mapping: Two pilot projects to determine how best to approach hazard mapping related to expansive soils and to produce demonstration products are proposed. One should be in the more humid eastern part of the state, the other in the more arid west. The Colorado Geological Survey has produced expansive-soil hazard maps in eastern Colorado. The Colorado maps can serve as guides for developing similar hazard maps modified for conditions in western Kansas. Susceptibility to expansive-soil problems should be mapped at 1:36,000 to 1:50,000 for urban areas and 1:100,000 for rural areas.

Research: The preceding discussion highlights the need for collecting the basic data required to establish the potential risk from expansive soils.

Research is needed into the probability of expansive-soil problems. Every year, structures are damaged by expansive soils. Some years, especially during droughts in the eastern part of the state, the damage may become widespread and have a significant economic impact. Studies are needed into causal factors, triggering mechanisms, and frequency of catastrophic events throughout Kansas.

Research is needed into the source of the expansive clays in the soils and the conditions that lead to concentrations of expansive minerals in the soil and sediment.

Prediction and monitoring: Because major expansive-soil problem events are most likely associated with drought conditions in the eastern portion of the state and wet climatic conditions in the west, warnings could be tied to drought forecasts in the east and to soil-moisture conditions in the west.

Public outreach: A KGS Public Information Circular is needed on expansive-soil problems. Colorado has a homebuyer's booklet on expansive soils. Kansas should follow the Public Information Circular with a homebuyer's guide that is customized for the problems in Kansas.

Streambank erosion

Streambank erosion occurs when a stream erodes the channel walls causing the channel to widen or migrate. It is a natural process for the channel of a meandering stream to migrate by streambank erosion. However, streambank erosion removes agricultural land and can destroy transportation systems and utility lines (fig. 5). Douglas County and the U. S. Army Corps of Engineers are conducting a study to stabilize a streambank where channel migration is encroaching on a road near Eudora (Miller, 2000). It is estimated that the stabilization of the streambank will cost between 1.3 and 1.6 million dollars. A farmer near St. Marys has lost between 50 and 100 acres of farmland along with his center-pivot irrigation system since 1993 due to channel migration along the Kansas River. Evidence for streambank stabilization can be seen along most rivers in the state. Channel widening along the Cimarron River in southwest Kansas has resulted in the loss of farmland and the replacement of bridges (McLaughlin, 1947).

The Corps of Engineers has investigated streambank erosion along the Kansas River (United States Army Corps of Engineers, 1978). As part of this study, Dort (1976) published maps showing channel migration and historical changes in the channel of the Kansas River and its tributaries. These maps show that the channel of the Kansas River is quite active. The reasons for this activity include natural migration of the channel, the dams along the major tributaries, natural and human-made restrictions in the channel, and dredging of sand and gravel from the channel (Ostercamp et al., 1981; McCrae, 1953). A factor not mentioned in the Corps of Engineers report is that channelization will cause active channel migration upstream and downstream of the stabilized reach.

Streambank erosion occurs every year. It increases during periods of high discharge primarily in the spring. The area affected by streambank erosion is the floodplain near the stream. Thus, damage due to streambank erosion may be less frequent. Because of a lack of data on damaging events caused by streambank erosion, the frequency was estimated to be in the tens of years (decades). However, a farmer losing land every year might argue for a yearly frequency.

Figure 5.—Abandoned bridge due to channel widening along the Nemaha River in southeastern Nebraska. The initial bridge, the largest truss span, spanned the channel when it was constructed. The bridge supports that appear to be trestle bents were originally I-beams driven into the alluvium on opposite sides of the channel. As the river widened its channel, additional truss spans were added until the bridge was abandoned.

The distribution is variable. The areas affected by streambank erosion are along the streams. The further a structure is away from the stream, the less likely it will be damaged by streambank erosion. Individual areas of streambank erosion affect moderate-sized areas (tens of acres). Cumulatively, streambank erosion may affect large areas (hundreds of acres) every year.

The risk rating for damage from streambank erosion is based on a frequency in decades (2), localized distribution (1), and moderate damage area (3) that results in a risk rating of 6. However, these values are highly speculative.

Streambank-erosion hazard needs:

Hazard mapping: Mapping on the extent of streambank erosion in the state is needed. The Kansas River was mapped but these maps need updating. The Cimarron River has been studied, but no detailed mapping was done with that study.

The need for streambank-erosion hazard maps is unclear. The areas with the active streambank erosion are for the most part in the 100-year floodplain. Thus, these areas are already highlighted on flood-hazard maps. Streambank erosion triggers landslides that should be identified on landslide-hazard maps. A demonstrated need for streambank-erosion hazard maps exists where structures must be sited close to streams—for example transportation systems, utility lines, and waste-treatment plants. A pilot study along the Kansas River would clarify the need for hazard maps.

Research: Studies of the material properties of the alluvium that control the susceptibility to streambank erosion are needed. It seams that the most active streambank erosion occurs in areas with the youngest alluvium. These areas would represent a zone of high hazard. Research is needed into the rate of streambank erosion and the factors that control the rate of erosion. This research would produce data on the probability of future streambank problems.

Prediction and monitoring: The opportunities exist for establishing a streambank-erosion monitoring project and conducting real-time monitoring of erosion near critical facilities and infrastructure. Streambank erosion is probably highest during floods and periods of sustained high discharge. Research could be used to develop a warning scheme for streambank erosion.

Public outreach: Public outreach needs in this area are unclear.

Mitigation and remediation: Streambank erosion has an economic impact when it weakens a bridge, removes a section of road, and destroys utilities and cropland. A need exists for developing mitigation strategies and remediation measures for streambank erosion.

Piping and hydrocompaction

Piping is the subsurface erosion of silt and expansive clay by ground-water flow. This is different from stream erosion, gullying, and sheet wash that occur when water flowing on the ground surface erodes the soil and rock. Piping in earthen dams has caused dams to fail, and piping along with stream erosion causes headward (upstream) extension of gullies. The common practice of dumping cobbles and boulders in streams to stop headward erosion has no effect on erosion by piping.

The NRCS county soil reports have some information about piping of soils related to the usefulness of a soil series as a construction material for earthen dams. Other than that, no studies of piping exist in Kansas. No data exist on damages piping might be causing and how piping affects gullying and soil loss. Due to a lack of data, no risk rating is assigned to piping.

Hydrocompaction occurs in soils in arid regions where the addition of water to the soil causes the soil structure to collapse, which leads to settlement and land subsidence. No reports of hydrocompaction exist in Kansas. If hydrocompaction exists in Kansas, the most likely area would be western Kansas. No risk rating is assigned to hydrocompaction.

Piping and hydrocompaction hazard needs:

This report is based on data available at the Kansas Geological Survey. No attempt was made to contact the Kansas Department of Transportation or the NRCS. Both of those agencies may have additional data on these geologic hazards. For example, piping may lead to pavement failures in highway embankments, and Kansas Department of Transportation might have some data on failures and repair costs.

Research: An assessment of the risk factor for piping and hydrocompaction is needed. This might be done in conjunction with Kansas State University Research and Extension. Based on the above assessment, research needs for these hazards can be defined.

Multiple Hazards:

Several natural hazards may result from the same trigger. A severe storm may produce a flood, cause erosion along the streambanks, and trigger landslides. Droughts can cause wind erosion, crop damage, and settlement in areas of expansive soils. Some areas that are susceptible to landslides also are susceptible to damage from expansive soils. As hazard mapping is completed, these interrelationships should be highlighted.

Research: Develop a statewide database on the mechanical properties of geologic materials by collecting existing rock- and soil-mechanical property data from engineering reports and supplementing it with additional testing as needed.

Mitigation and remediation: Mitigation strategies must be developed that address all potential hazards. Moving someone from a floodplain and allowing them to settle on a landslide may not reduce their risk.

Geologic Hazard Mapping Program for Kansas

On-going activities 2000-01

Landslide mapping has begun in Leavenworth County at 1:24,000 scale. This includes an inventory and susceptibility maps similar to those developed for the City of Atchison. The goal is to publish the landslide maps and a report on landslides of Leavenworth County in 2001.

Paleoseismology mapping is continuing along streams in the area of the Humboldt fault and Nemaha anticline. Primarily, the fieldwork involves locating areas of liquefaction and detailed mapping of faults. Liquefaction studies will continue and the region of investigation will be expanded in 2001. If liquefaction features remain elusive, a progress report will be published in the open-file series in 2001.

Structural-geology studies related to neotectonics in the Manhattan 1° x 2° quadrangle are continuing. Detailed mapping of structures will provide insight into the tectonic setting of Kansas. This will help us locate faults that could potentially produce earthquakes. Mapping is continuing with results expected in 2001.

Five-year plan for hazard studies

Landslide-hazard mapping: With the anticipated completion of the landslide-hazard pilot project in Atchison, the products can be shown to city and county officials to determine their interest in having landslide-hazard maps of their jurisdictions and their interest in supporting this mapping. The cities and counties include the unified government of Kansas City, Kansas, and Wyandotte County; Johnson County and its cities; and Douglas County and Lawrence. The goal would be to produce landslide maps and the accompanying reports by 2005. The final publication will be a Kansas Geological Survey Bulletin on the landslides of the Kansas City metropolitan area with an estimated completion date of 2005.

Landslide research: A need exists for studies on the mechanics and triggering of landslides. Plans are underway to develop an externally funded program that will examine the relationship between precipitation, deep ground-water flow, and the triggering of landslides. This will be a multi-year program that will support at least one graduate student. Other landslide-mechanics proposals may follow.

Paleoseismology: Plans are to continue examining streams and rivers for liquefaction features and Quaternary deposits for faults. The anticipated completion date is 2005. If evidence of prehistoric earthquakes can be found, then the potential exists for funding through National Earthquake Hazard Reduction Program (NEHRP) of the USGS.

Earthquake-hazard mapping: A program will be initiated to map areas susceptible to ground failure during an earthquake. Missouri and several other states will soon have earthquake-hazard maps that were produced by the Central United States Earthquake Consortium (CUSEC). The Kansas Geological Survey will submit a proposal to NEHRP to produce earthquake-hazard maps for northeastern Kansas similar to those produced by CUSEC. Prior to writing this proposal the Kansas Geological Survey, staff needs to learn the procedures used to generate the CUSEC maps and determine if the required data are available for the proposed study area.

Expansive soils: Prior to 2005, A KGS Public Information Circular will be written on expansive soils. A pilot project on mapping hazard areas in eastern Kansas for expansive soils will be initiated sometime prior to 2005. This project will involve examining soils and rocks for swelling potential and using the distribution of soil and rock units as a guide to areas that are susceptible to expansive-soil damage.

Areas of future studies:

The following include areas for hazard studies in the future. Some of the following could be added to the five-year plan if the Kansas Geological Survey increases staffing in the area of engineering geology.

Flooding: Jurisdictions that are involved in the FEMA flood-insurance program have flood-insurance-rate maps. Some flood-insurance-rate maps require updating. Research on the effects of urbanization and flooding with emphasis on the urban areas of Kansas would be useful. Another area of potential research involves using natural systems to mitigate flooding.

Wind erosion: Wind erosion is a priority for the western part of the state, and in the past has been handled by the Department of Agriculture. There may be areas of collaborative research that could be pursued by the Kansas Geological Survey in the future.

Earthquakes: Earthquake studies are currently in the active projects and in the five-year plan.

Landslides: Landslides studies are currently in the active projects and in the five-year plan.

Expansive soils: Initial work on expansive-soil hazards should begin as part of the five-year plan. Further studies would include publishing a homebuyer's guide to expansive-soil problems, initiating a pilot project in western Kansas possibly in cooperation with Fort Hays State University, and producing expansive-soil hazard maps.

Land subsidence: The state needs a basic report on land subsidence associated with coal mining. Additionally, land-subsidence hazard maps are needed for areas of natural and human-influenced dissolution of salt, natural caverns in limestone and gypsum, and underground mines. Geophysical studies have proven to be good tools to use on site-specific problems, for example the formation of a sinkhole by salt dissolution. However, for regional studies, remote-sensing approaches may produce better results. At some point the Kansas Geological Survey may want to evaluate the potential for land subsidence from ground-water mining.

Piping, hydrocompaction, and streambank erosion: An initial assessment of the risk from piping, hydrocompaction, and streambank erosion is needed. Based on this assessment, research and hazard needs in these areas can be determined.

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