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PAPER

The current status of mapping karst areas and availability of public sinkhole-risk resources in karst terrains of the United States

Eve L. Kuniansky[1] **· David J. Weary**[2] **· James E. Kaufmann**[3]

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Abstract Subsidence from sinkhole collapse is a common occurrence in areas underlain by water-soluble rocks such as carbonate and evaporite rocks, typical of karst terrain. Almost all 50 States within the United States (excluding Delaware and Rhode Island) have karst areas, with sinkhole damage highest in Florida, Texas, Alabama, Missouri, Kentucky, Tennessee, and Pennsylvania. A conservative estimate of losses to all types of ground subsidence was $125 million per year in 1997. This estimate may now be low, as review of cost reports from the last 15 years indicates that the cost of karst collapses in the United States averages more than $300 million per year. Knowing when a catastrophic event will occur is not possible; however, understanding where such occurrences are likely is possible. The US Geological Survey has developed and maintains national-scale maps of karst areas and areas prone to sinkhole formation. Several States provide additional resources for their citizens; Alabama, Colorado, Florida, Indiana, Iowa, Kentucky, Minnesota, Missouri, Ohio, and Pennsylvania maintain databases of sinkholes or karst features, with Florida, Kentucky, Missouri, and Ohio providing sinkhole reporting mechanisms for the public.

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✉ Eve L. Kuniansky
elkunian@usgs.gov

[1] US Geological Survey, 1770 Corporate Drive, Suite 500, Norcross, GA 30093, USA

[2] US Geological Survey, MS926A National Center, 12201 Sunrise Valley Drive, Reston, VA 20192, USA

[3] US Geological Survey, Earth Resources Observation and Science Center, 19986 State Route F, Saint James, MO 65559, USA

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Introduction

Subsidence from sinkhole collapse is a common occurrence in areas underlain by water-soluble rocks such as carbonate and evaporite rocks, typical of karst terrain, a landscape with features such as sinkholes, sinking streams, and springs, which reflect the presence of subsurface voids or caves (Ford and Williams 2007). The term "karst" has been widened to include both features that reflect surficial dissolution processes (epigenic karst), and more recently, features that reflect dissolution processes at depth (hypogenic karst); both result in subsurface voids with the potential for subsidence, sudden sinkhole collapse, or cave development (Palmer 1991, 2000; Klimchouk 2007; Palmer and Palmer 2009, 2011).

There are different classifications of sinkhole types. Waltham et al. (2005) defined six classes: solution, collapse, caprock, dropout, suffosion, and buried (Table 1; Fig. 1a). An illustration from a poster from the Florida Geological Survey shows slightly different sinkhole types (Rupert and Spencer 2004) common in Florida (Fig. 1b). Robertson and Orndorff (2013) lumped sinkholes into two major types: cover-collapse and cover subsidence; cover-collapse includes sinkholes that form over a period of hours or days resulting in often catastrophic damage, and cover-subsidence sinkholes form slowly over time resulting in the gradual subsidence of the ground. Tihansky (1999) categorized the three main sinkhole types in Florida (dissolution, cover-subsidence and cover-collapse) that develop from the processes of dissolution and suffosion, noting that some sinkholes are a combination of types and can form in different phases. All sinkholes in karst require dissolution of soluble rocks. Suffosion is the process where

Table 1 Six types of sinkhole as classified by Waltham et al. (2005) indicating processes, rock types, and formation speed (modified from Waltham et al. 2005)

Type of sinkhole	Formation process	Host rock type	Formation speed	Typical maximum size	Engineering hazard	Other sinkhole names in use
Solution sinkhole	Dissolutional lowering of surface	Limestone, dolomite, gypsum, salt	Stable landforms evolving over >20,000 years	Up to 1,000 m across and 100 m deep	Fissure and cave drains must exist beneath floor	Dissolution, cockpit, doline
Collapse sinkhole	Rock roof failure into underlying cave	Limestone, dolomite, gypsum, basalt	Extremely rare, rapid failure events, into old cave	Up to 300 m across and 100 m deep	Unstable breakdown floor; failure of loaded cave roof	Cave collapse, cenote
Caprock sinkhole	Failure of insoluble rock into cave in soluble rock below	Any rock overlying limestone, dolomite, gypsum	Rare failure events, evolve over >10,000 years	Up to 300 m across and 100 m deep	Unstable breakdown floor	Subjacent collapse, interstratal karst
Subsidence sinkhole -dropout	Soil collapse into soil void formed over bedrock fissure	Cohesive soil overlying limestone, dolomite, gypsum	In minutes, into soil void evolved over months or years	Up to 50 m across and 10 m deep	The main threat of instant failure in soil-covered karst	Subsidence, cover collapse, alluvial
Subsidence sinkhole -suffosion	Down-washing of soil into fissures in bedrock	Non-cohesive soil over limestone, dolomite, gypsum	Subsiding over months or years	Up to 50 m across and 10 m deep	Slow destructive subsidence over years	Subsidence, cover subsidence, alluvial
Buried sinkhole	Sinkhole in rock, soil-filled after environmental change	Rockhead depression in limestone, dolomite, gypsum	Stable features of geology, evolved over >10,000 years	Up to 300 m across and 100 m deep	Local subsidence on soft fill surrounded by stable rock	Filled, compaction, paleo

surficial unconsolidated sediments infill voids below and can occur catastrophically (cover-collapse sinkhole) or gradually (cover-subsidence sinkhole) over time. It is the rapidly occurring dropout or cover-collapse sinkhole that is most dangerous.

Studies in Florida indicate an increase in the frequency of sinkhole formation corresponding to the increase in groundwater development, drilling, surface loading, urban expansion into previously undeveloped sinkhole-prone areas, and drought-precipitation extremes (Wilson and Shock 1996; Tihansky 1999). Both drought and increasing groundwater development lower groundwater levels resulting in increased effective stresses on the supporting rock and drainage of water-filled submerged caverns, all of which can result in increases in sinkhole formation. Additionally, precipitation extremes, especially following a period of drought or immediately following flooding, correlate with an increase in karst sinkhole formation. Urban expansion into karst areas often results in the discovery of sinkholes and other karst features. Additionally, construction and well drilling can change groundwater levels and recharge patterns, both of which can induce sinkholes in karst areas. There is ongoing confusion among non-geologists as to what constitutes a sinkhole. The news media, utility workers, and highway engineers often refer to any localized ground collapse as a 'sinkhole'. Often these collapses are caused by leaking water, sewer, or drainage pipes and are not genetically related to karst sinkholes. In some cases, however, these artificial 'sinkholes' can occur over karst terrains, or in conjunction with karst processes, making their true causation ambiguous.

The destruction of life and property is an obvious hazard from the sudden collapse and subsidence when a sinkhole forms beneath structures. Almost all 50 states within the United States (US) have karst areas (exceptions are Delaware and Rhode Island), with the greatest amount of karst sinkhole damage occurring in Florida, Texas, Alabama, Missouri, Kentucky, Tennessee, and Pennsylvania (in decreasing order of damage). Florida is at the greatest risk and has the most frequent occurrences of sinkholes as the entire state is underlain by surficial or fairly shallow carbonate rocks over 1,000 m thick (Williams and Kuniansky 2015). During periods of surface exposure, precipitation of weak carbonic acid rainfall can aggressively dissolve carbonate rocks, thus there is both paleokarst and current karst development. The Federal Emergency Management Agency (FEMA 1997) conservatively estimated losses attributed to all types of ground subsidence to be at least $125 million per year in the US. A review of publically available cost reports from the past 15 years indicates that the cost of karst collapses in the US averages at least $300 million per year. Much of the cost is incurred in Florida where insurance sources reported more than $84 million in sinkhole losses plus adjustment expenses in 2009. The Florida Office of Insurance Regulation (2010) reported that

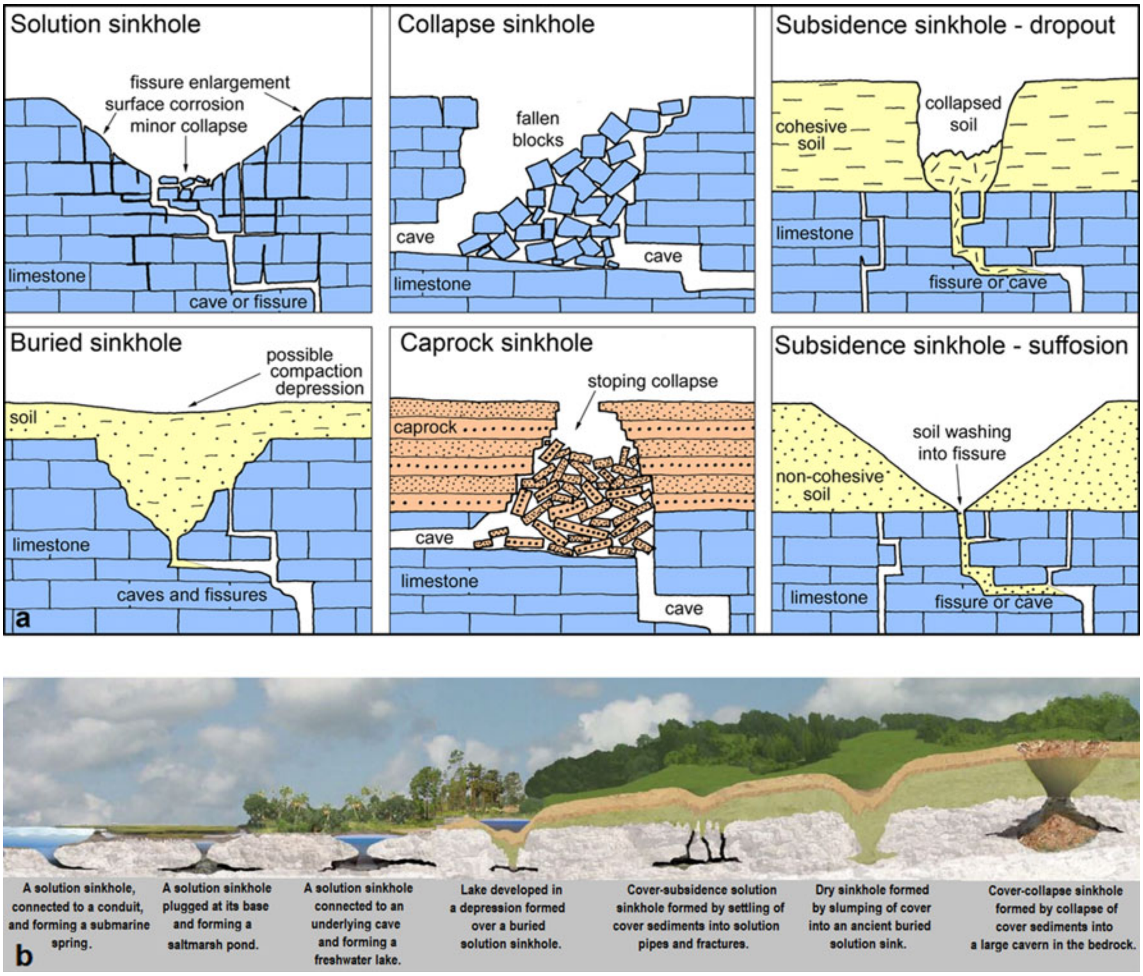

Fig. 1 **a** Cross-sectional diagrams for six types of sinkholes defined by Waltham et al. (2005) described in Table 1 (illustration provided by Tony Waltham, written communication, 2015) and **b** illustration of sinkholes in Florida (modified from Rupert and Spencer 2004)

insurers had received 24,671 claims for sinkhole damage in Florida between 2006 and 2010 totaling $1.4 billion, an average of $280 million per year for those 5 years. Cost per year in Florida is on an increasing trend with total sinkhole losses for closed and open claims combined increasing from $209 million in 2006 to $406 million in 2009 (The Florida Senate 2010).

The depositional environments, diagenetic processes, post-depositional tectonic events, and geochemical weathering processes that form karst aquifers and landforms are varied and complex, and involve biological, chemical, and physical changes. The complex hydrogeologic systems in karst terrain represent challenging and unique conditions for engineers and scientists attempting to mitigate hazards posed by sinkholes and subsidence. Waltham et al. (2005) published a textbook on the engineering issues related to subsidence and sinkholes in karst and cavernous rocks. The Florida Geological Survey published a report on how to evaluate sinkholes (Schmidt 2005). The states with the greatest sinkhole hazard risk in the aforementioned provide useful information on the science of sinkholes on their websites.

In the US, the unique challenges posed by sinkholes resulted in the late Barry Beck developing a series of multidisciplinary conferences entitled “Sinkholes and the Engineering and Environmental Impacts of Karst.” There have been 13 conferences convened since 1984 (Beck 1984, 1989, 1993, 2003, 2005; Beck and Wilson 1987; Beck and Pearson 1995; Beck and Stephenson 1997; Beck et al. 1999; Beck and Herring 2001; Land et al. 2013; Yuhr et al. 2008, 2011) with conferences held every 2 years. The environmental problems related to karst sinkholes are substantial, owing to the increased vulnerability of groundwater from rapid infiltration of surface water through sinkholes. The transfer of anthropogenic contaminants resulting in water-quality degradation near sinkholes is well understood, such that aquifer vulnerability assessments in karst terrain generally include geospatial analysis of sinkhole distribution (Arthur et al. 2007; Lindsey et al. 2010). Numerous publications are devoted to understanding speleogenesis, geomorphology, and hydrogeology of karst landscape and aquifer systems (Sweeting 1973; Jakucs 1977; Bögli 1980; Jennings 1985; Trudgill 1985; Watson and White 1985; Dreybrodt

1988; White 1988; Ford and Williams 1989; Lowe 1992; Shaw 1992; Klimchouk et al. 2000).

Numerous government agencies in the US, both federal and state, provide detailed information on the location of karst areas and areas prone to sinkhole development. While this information does not make it possible to know when a catastrophic sinkhole event will occur, it does provide critical spatial detail on where sinkhole development has occurred and is likely to occur in the future. The purpose of this paper is to describe the current status of mapping karst areas, but focuses on sinkhole risk areas in the US and the availability of associated public resources such as sinkhole mapping efforts and databases.

National mapping of karst and potential sinkhole risk areas

Maps of karst areas and their associated engineering aspects have been developed and published at the scale of the entire United States (Davies and LeGrand 1972; Davies et al. 1984). The work of Davies et al. (1984) was published as a digitally available geospatial dataset by Tobin and Weary (2004). In 2014, the US Geological Survey (USGS) provided a digital version of updated maps showing areas of soluble rocks based primarily on updated state geologic maps of rock units containing substantial amounts of carbonate or evaporite minerals (Weary and Doctor 2014). The digital map data were compiled from a series of integrated geologic map databases for the US and produced by the USGS Mineral Resources Program (USGS 2014). The main source of original data for the Minerals Resources Program is state geologic maps at scales ranging from 1:250,000 to 1:1,000,000. Use of the USGS digital geologic data provided a consistent data structure within which a derivative database of areas having potential for karst could be constructed. Edits, deletions, and additions to this database were made based on (1) comparison to other published karst maps (principally Davies et al. 1984; Veni 2002); (2) comments and contributions by other cave and karst researchers having local knowledge of particular areas, and assisted by the comprehensive compilation in Palmer and Palmer (2009); and (3) the professional judgment of the authors (Weary and Doctor 2014). Further characterization of the karst areas was also accomplished via overlay analyses with other data, including distribution of glacially derived sediments (Soller et al. 2012) and Level III Ecoregions (US Environmental Protection Agency 2013). The purpose of the USGS mapping is to delineate the distribution of karst, potential karst, and pseudokarst (non-dissolving rock terrain with sub-surface drainage such as volcanic terrain with lava tubes) areas of the US. Because the data are compiled from a variety of sources with differing scales, various geologic datasets, spatial errors and location inconsistencies, the resulting mapping should not be used for site-specific application (Weary and Doctor 2014). Figures 2 and 3 show the national-scale mapping of karst areas of the United States.

Areas of outcrop and near-surface evaporite rocks and the extent of subsurface evaporite basins are mapped for the conterminous US (Weary and Doctor 2014). “The evaporite basins contain soluble rocks buried to depths of as much as 7, 000 ft, but generally much less. Because of the physical properties and very high solubility of evaporite rocks, human activities such as fluid injection, or the occurrence of leakage from well casings, can induce the formation of large solution voids. Collapses of these voids are known to propagate up to the surface from depths of more than 1,000 ft.” (Weary and Doctor 2014). The extent of the evaporite basins is derived in part from information provided in Dunrud and Nevins (1981) and Johnson (2007).

The combination of Figs. 2 and 4 provides the best delineation of areas in the contiguous US where sinkholes and subsidence from dissolution of rocks are possible. However, these maps cannot replace local and state agency data on sinkhole occurrence. In the Florida peninsula, deeply buried evaporite rocks are present (Fig. 4), but sinkhole formation at land surface has no known relationship with these deeply buried evaporite deposits. The newer digital maps published by the USGS (Weary and Doctor 2014) provide a valuable resource for the public and are largely a result of the USGS National Cooperative Geologic Mapping Program, which relies on federal, state, and university partners to deliver these digital geologic map products (USGS 2015a).

Aside from distributing maps of karst and evaporite areas, the USGS has assisted news agencies with information about sinkholes and developed educational materials about karst in general and sinkholes in particular. Shortly after the catastrophic sinkhole collapse of February 28, 2013, in Florida that resulted in the death of one man, Robertson and Orndorff (2013) posted an article online on March 11, 2013, describing the occurrence and causes of sinkholes. The USGS developed educational training materials on karst topography for use by teachers for grades 5–12 (Alpha et al. 1997). Additionally, the USGS Water Science School website has a page dedicated to sinkholes and is available online (USGS 2015b).

State resources

All 50 states have contributed to geologic mapping in the US through the National Cooperative Geologic Mapping Program, which is the “primary source of funds for the production of geologic maps in the United States and provides accurate geologic maps and three-dimensional framework models that help to sustain and improve the quality of life and economic vitality of the Nation and to mitigate natural

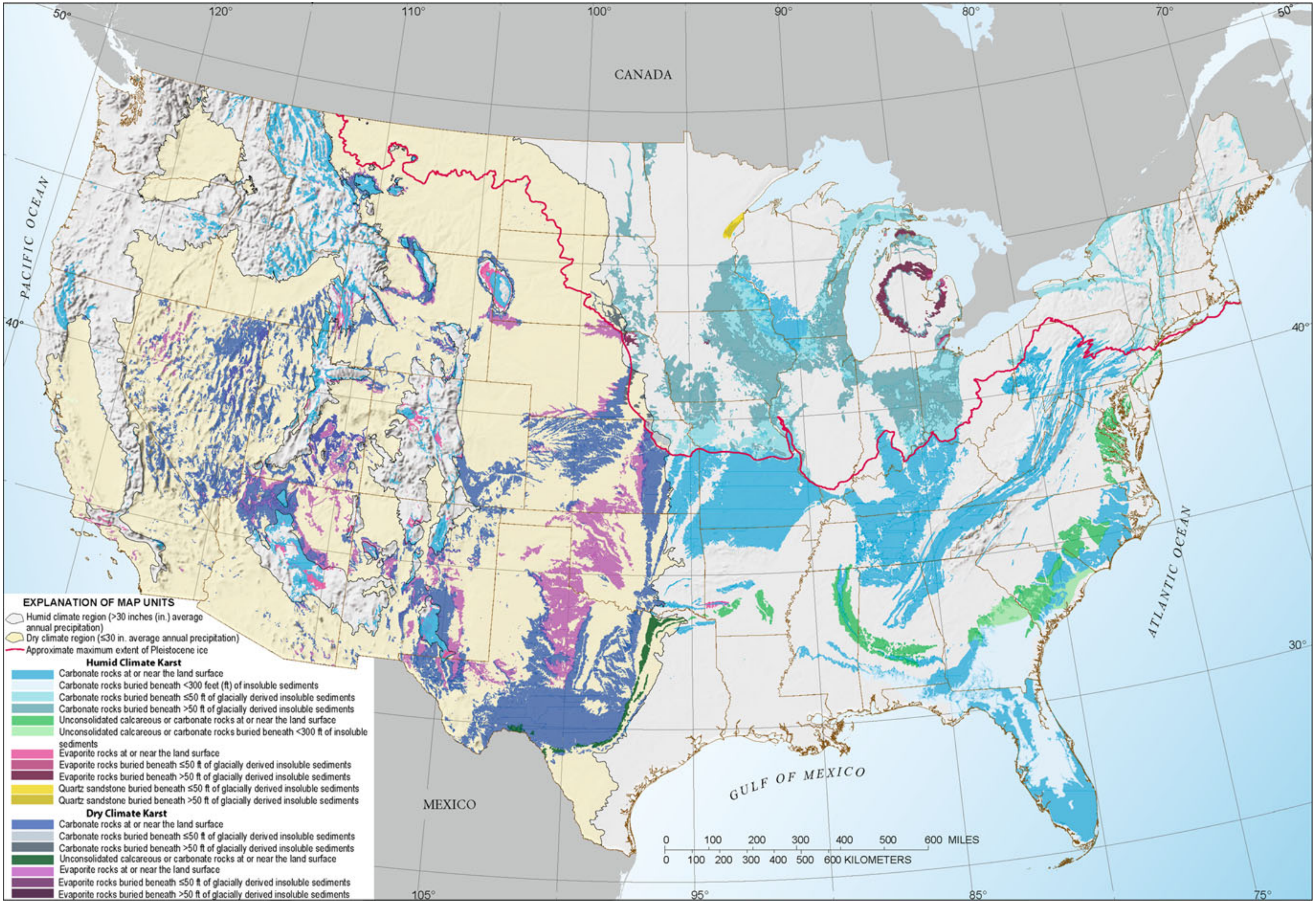

Fig. 2 Karst and potential karst areas in soluble rocks in the contiguous United States (modified from Weary and Doctor 2014)

Fig. 3 Karst and potential karst areas in soluble rocks in **a** Alaska; **b** Hawaii; and **c** Puerto Rico and the US Virgin Islands (modified from Weary and Doctor 2014)

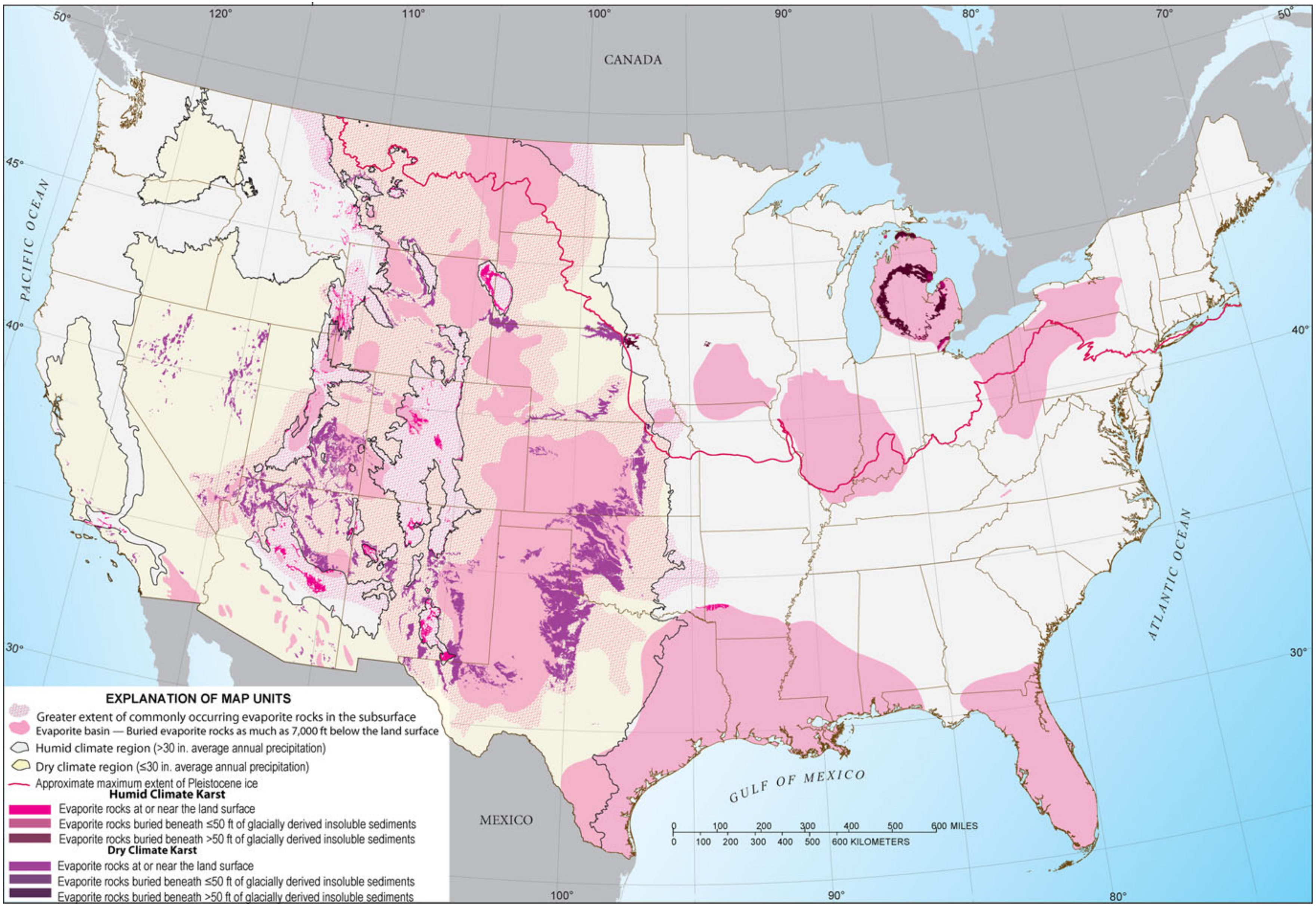

Fig. 4 Areas underlain by evaporite rocks at various depths up to 7,000 feet (2,000 m) below the land surface in the contiguous United States (modified from Weary and Doctor 2014)

hazards (USGS 2015a)". Many of these maps fed into the derivative national-scale mapping of karst discussed in the previous section. While all states have mapped carbonate and evaporite rocks, not all have developed sinkhole risk maps or maintain databases of sinkholes. The National Cave and Karst Research Institute (NCKRI) maintains a website that has links to each state agency involved in geologic mapping and links to the state webpages for geologic hazards, karst, or sinkholes and subsidence, if available (NCKRI 2015). Alabama, Arizona, Florida, Illinois, Indiana, Iowa, Kentucky, Maryland, Minnesota, Missouri, Ohio, Pennsylvania, Texas, Virginia, West Virginia, and Wisconsin have links from the NCKRI website to either geologic hazards, sinkholes, or karst mapping.

Alabama, Florida, Kentucky, Minnesota, Missouri, and Pennsylvania maintain state databases of sinkholes or karst features, with Florida, Kentucky, Missouri and Ohio also maintaining sinkhole-reporting mechanisms for the public. Maryland provides information about karst sinkholes through the Maryland Geological Survey website. Locating publicly available resources for each state is not straight forward, and was accomplished from knowledge of the authors and searches of the Internet from the US Government's open data web service (USA 2015), searches of the USGS ScienceBase-Catalog (USGS 2015c), and searches using web searching tools such as Google and Bing with terms such as karst and sinkhole. Additionally the links from the NCKRI website mentioned in the previous were checked for sinkhole resources in each state.

Florida has delineated areas of different sinkhole types and risks, and Alabama has developed a sinkhole density map. In advising the public on steps to take upon discovering a sinkhole, most states provide guidance similar to that provided in Alabama: (1) place a barrier around the sinkhole to warn people of the sinkhole; (2) contact your homeowner's insurance company; (3) depending on how close the sinkhole is to a building, consider contacting a geologist, engineer, or foundation specialist; (4) if the sinkhole is affecting public property or safety (parks, sidewalks, water or sewer drainage), consider contacting city or county department of public works or engineering department; (5) if the sinkhole is affecting a public road or highway, contact the Department of Transportation (modified from website Geological Survey of Alabama (2015).

More details about public information available on websites from the states of Alabama, Colorado, Florida, Illinois, Indiana, Iowa, Kentucky, Maryland, Minnesota, Missouri, Ohio, Pennsylvania, Tennessee, and Texas follow in the subsequent sections. Note that not all state resources are provided; however, the full range of types of available public information from states is provided, such as Florida, with extensive information provided on karst features and sinkhole-reporting mechanisms for the public, to Maryland, which provides a map of karst area and information on who to contact if a sinkhole is suspected. Additionally, the sources of publicly available information at the state level vary from caving societies to state geological surveys within universities, to state geological surveys within state governments or departments of natural resources.

The Geologic Survey of Alabama maintains a website on sinkholes and karst as part of their Geological Hazards Program (Geological Survey of Alabama 2015), which has a link to the data shown on a map of naturally occurring sinkholes (Ebersole and Tavis 2010).

Colorado's Natural Hazards Mitigation Plan includes hazards due to subsidence attributable to natural karst processes and related to mining activities (Colorado Division of Homeland Security and Emergency Management 2013). As part of the hazard plan, the Colorado Geological Survey has produced a map of evaporite karst subsidence hazards (White 2012). The map includes downloadable geographic information system (GIS) files.

The Florida Geological Survey (FGS) has a website devoted to providing an understanding of the occurrence of sinkholes (FGS 2012a). The USGS, as part of a cooperative program with the FGS, published a statewide map recognizing four geological settings associated with predominant sinkhole types in Florida as follows (Sinclair and Stewart 1985): (1) gradual development of solution sinkholes dominate; (2) cover-subsidence sinkholes dominate; (3) numerous abrupt cover-collapse sinkholes dominate; (4) deep cover-collapse sinkholes dominate. The areas delineated by Sinclair and Stewart (1985) are not aligned with sinkhole observations in more recent years, but do provide valuable data on the predominant sinkhole types. A database of sinkholes was first published by the FGS (Spencer and Lane 1995) and called "Florida Sinkhole Index". This original database was compiled from a voluntary public reporting mechanism and not all sinkholes were assessed by a professional geologist, and thus included non-karst-related sinkholes. The FGS abandoned the name "Florida Sinkhole Index", and having renamed it, now maintains a database of "Subsidence Incidence Reports." Additionally, the FGS has an online form (FGS 2012b) for citizens to report subsidence incidents and currently maintains an online database of these reports with a disclaimer indicating that many of these incidents are not field checked by a qualified geologist or engineer. In 2013, the FGS received $1.1 million to develop a scientifically defensible sinkhole vulnerability map and develop new standards for sinkhole-vulnerability studies (FLDEP Press Office 2013; Kromhout and Baker 2014; Witze 2013). The FGS provides a graphic user interface named Map Direct for the subsidence incidence database and multiple karst or karst-related features such as swallets (sinking streams), springs, springs protection areas, and other spatial datasets (FGS 2015).

In 1990, the Florida Legislature discontinued funding to the Florida Sinkhole Research Institute and transferred these responsibilities to the FGS, which has a public webpage devoted to frequently asked questions of which the first 26 relate to sinkholes (FGS 2012c).

The Illinois State Geological Survey has produced a guidebook on the Illinois sinkhole plain, a classic karst terrain of the Midwest (Panno et al. 2011), and has a sinkhole area map available online. The Indiana Geological Survey (IGS) makes several karst datasets available through a public Geographic Information System Portal, IndianaMAP (2015), including sinkhole areas and points (IGS 2015). Cave density, the number of mapped cave entrances per square kilometer, is also available.

Iowa's Department of Natural Resources (Iowa DNR) maintains a dataset of current and historic sinkholes through the Iowa State University GIS Support and Research Facility (Iowa DNR 2015). The dataset includes current and historic mapped sinkholes and depressions in the form of a point dataset and a polygon dataset, indicating the boundary of the sinkhole if this boundary could be delineated with Lidar (light detection and ranging) data. These data are used by the Iowa Department of Natural Resources for enforcement of the Iowa Administrative Code, which prohibits new confined animal feeding operations (CAFOs) or expansion of existing CAFOs from constructing earthen basins for manure storage in karst terrain. The regulation of land use and construction is defined by local or state government and thus the Iowa Administrative Code applies only to Iowa.

The Kentucky Geological Survey (KGS) maintains an online sinkhole dataset (KGS 2015a) and a webpage with valuable resources about karst (KGS 2015b) with links to specific information on sinkhole flooding and cover-collapse sinkholes, and vulnerability to pollution. Additionally, the KGS has online forms available for the public to report cover-collapse sinkholes (KGS 1997). Within the Maryland Department of Natural Resources, the Maryland Geological Survey (MDGS) maintains a website with information to assist the public if a sinkhole or suspected sinkhole occurs (MDGS 2015). The website provides a link to online karst maps, which can be used to determine if the suspected sinkhole is in a karst area in western Maryland and then which state or local agencies can provide technical assistance.

The Minnesota Department of Natural Resources (MNDNR) maintains an online karst feature inventory points of springs, sinks, and sinkholes (MNDNR 2015). The database description was published in Gao et al. (2002). The Missouri Geological Survey (MOGS) has a program for documenting sinkholes and has verified 15,981 sinkholes in Missouri (MOGS 2015). The USGS developed a fact sheet to help explain the catastrophic collapse sinkholes that can form in the karst terrain of Missouri (Kaufmann 2007).

The Ohio Geological Survey (OGS) has a geologic hazards program with karst mapping resources for the public. Within this program is a website for reporting sinkholes, caverns, or other karst features (OGS 2015a). The fill-in form is used to support the OGS in mapping karst features across Ohio. Additionally, the OGS has published a map of karst areas within Ohio (OGS 1999) and has produced other publications on Ohio's karst geology website (OGS 2015b). The Pennsylvania Geological Survey (PGS) provides the public with online access to an interactive map of known sinkholes in south-central and southeastern Pennsylvania (PGS 2015). The website also provides links to technical reports describing the karst features and sinkholes located in these areas.

The Tennessee Geological Survey does not maintain a website specifically for geologic hazards or sinkholes, but does provide a public education publication devoted to the topic of subsidence and sinkholes in eastern Tennessee (Kohl 2001) and a geologic hazards map of Tennessee that includes sinkhole collapse and setting (Miller 1977). Additionally a report on sinkhole collapse in Montgomery County provides some criteria needed to identify sinkholes that are likely to collapse (Kemmerly 1980). A table and map of sinkholes with depths greater than 100 ft (30.5 m) in Tennessee is available online from a website maintained by Dunigan (2015). This website indicates that over 54,000 sinkholes are visible on USGS topographic quadrangle maps and shows images of sinkhole density. These online data for sinkholes and caves are provided by the Tennessee Cave Society and references a study by Shofner et al. (2001) that provides documentation on the development of the data and links to various sinkhole density map realizations for Tennessee.

The State of Texas does not maintain a database of sinkholes; however, the Bureau of Economic Geology has done research into collapse risk in evaporite sinkhole-prone areas (Paine et al. 2012) and a current program entitled "Field Validation of Geologic Assessment of Features Sensitive to Pollution in Karst and Development of Best Management Practices," specifically mentions conducting research on infiltration at sinkholes, but does not include mapping of sinkholes or sinkhole density within the state (Hovorka et al. 2005). The only statewide database that includes any karst features is a compilation of historical data at 2,000 springs in Texas (Heitmuller and Williams 2006).

Summary

Subsidence from sudden sinkhole collapse is a geologic hazard in karst areas of the United States resulting in estimated economic losses of more than $300 million dollars a year. States with the greatest amount of karst sinkhole damage are Florida, Texas, Alabama, Missouri, Kentucky, Tennessee, and Pennsylvania. Aside from economic damage associated with sudden sinkhole collapse, the environmental problems related to karst sinkholes are substantial owing to the increased vulnerability of groundwater from rapid infiltration of surface water through sinkholes. The transfer of anthropogenic contaminants resulting in water-quality degradation near sinkholes is well understood such that aquifer vulnerability assessments in karst terrain generally include geospatial analysis of sinkhole distribution (Arthur et al. 2007; Lindsey et al. 2010).

Sinkholes in karst terrain occur naturally and from anthropogenic activity. In Florida, increased rates of sinkhole formation correspond to the increase in groundwater development, drilling, surface loading, urban expansion into previously undeveloped sinkhole-prone areas and drought or precipitation extremes (Wilson and Shock 1996; Tihansky 1999).

At the national scale, the available public resources include maps of karst areas and their associated engineering aspects (Davies and LeGrand 1972; Davies et al. 1984) made digitally available by Tobin and Weary (2004). Additionally, the USGS provides a digital version of updated maps showing areas of soluble rocks based primarily on updated state geologic maps of rock units containing substantial amounts of carbonate or evaporite minerals (Weary and Doctor 2014). The digital map data were compiled from a series of integrated geologic map databases for the US produced by the USGS Mineral Resources Program (USGS 2014). More detailed geologic mapping is available from most state agencies. There is no national sinkhole hazards program or national sinkhole database.

Not all states with karst terrain and sinkhole risk have resources for the public. Most states with substantial damage attributed to karst sinkholes have public resources documenting the locations of sinkholes and/or sinkhole density, with the exception of Texas. Florida, the state with the greatest sinkhole damage in 2013, provided $1.1 million in funding to the Florida Geological Survey for developing a scientifically defensible sinkhole vulnerability map and new standards for sinkhole-vulnerability studies (FLDEP Press Office 2013; Kromhout and Baker 2014; Witze 2013).

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