Natural Hazard Mitigation Planning
For Karst Terrains in Virginia

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Natural Hazard Planning for Karst Terrains in Virginia

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(Abstract)

Amendments to the Robert T. Stafford Act require state and local governments to adopt natural hazard mitigation plans to qualify for pre- and post-disaster federal hazard mitigation funding. State and local governments must consider all potential hazards within their jurisdictions including flooding, hurricanes, blizzards, and earthquakes. In western Virginia, local governments should plan for karst terrain natural hazards.

Karst terrain hazards include sinkhole subsidence, sinkhole flooding, and groundwater contamination. Despite an extensive amount of karst terrain in many communities in western Virginia, few communities use comprehensive land use planning and management approaches for development on karst terrain. A survey of local governments in the karst belt of Virginia illustrates that few communities have gone farther than a brief reference to karst terrain in their comprehensive plans. The majority of local governments in the karst belt of Virginia have not developed comprehensive land use planning approaches for karst terrain despite the availability of a large number of potential planning options pioneered by other karst communities.

This paper proposes a process for karst terrain natural hazard mitigation planning in Virginia. The process begins with community education and partnership building to build community understanding and support for the various mitigation strategies applicable to local karst terrain hazard areas. Effective natural hazard assessment allows for the relatively precise targeting of regulatory and non-regulatory mitigation strategies to minimize the impact of land use restrictions on the general community, while maximizing the hazard mitigation efficacy of the chosen strategies.

Table of Contents

Chapter 1 – Introduction 1
Natural Hazard Mitigation Planning 2
What is a natural hazard? 2
Federal Guidelines for Natural Hazard Mitigation Planning 2
Conclusion 6

Chapter 2 – Karst Terrain Natural Hazards 7
Introduction 7
Sinkhole Subsidence 7
Sinkhole Flooding 8
Groundwater Contamination 9
Conclusion 11

Chapter 3 – Karst Related Land Use Planning in Virginia 12
Introduction 12
Karst Protection Survey 14
Karst Terrain Mapping and Geographic Information Systems 15
Comprehensive Plan 17
Capital Improvements Programming 17
Voluntary land use restrictions 18
Subdivision Regulation 19
Zoning Ordinance 19
Karst Related Zoning Overlay Districts 20
Karst Feature Buffers 20
Geotechnical Studies 20
Performance Standards 21
Stormwater Management and Erosion and Sediment Control 21
Water Supply Protection Policies 22
Enhanced Septic System Regulations 23
Other Karst Related Ordinances, Regulations, and Policies 24
Conclusion 25

Chapter 4 – A Process for Karst Hazard Mitigation Planning in Virginia 28
Introduction 28
Community Education and Partnership Building 29
Karst Terrain Hazard Risk Assessment and Vulnerability Analysis 31
Develop Regulatory Karst Terrain Hazard Mitigation Strategies 31
Develop Non-Regulatory Karst Terrain Hazard Mitigation Strategies 32
Model Karst Terrain Overlay and Buffering Hierarchy 32
Conclusion 34

Works Cited 36

Lists of Tables and Figures

Table 3.1 – Estimated Karst Terrain in Virginia Counties 14
Table 3.2 – Summary of Karst Protection Survey Findings 16
Table 3.3 – Examples of Septic System Regulation Enhancements 24
Table 3.4 – Sinkhole Classification Schemes 26
Table 3.5 – Summary of Planning Options for Managing Land Use in Karst Terrain 27
Table 4.1 – Karst Terrain Hazard Mitigation Plan Development Process 29
Table 4.2 – Potential Partners for Karst Terrain Hazard Mitigation Planning 30

Figure 1.1 – Risk diagram 3
Figure 2.1 – Clarke County sinkhole 8
Figure 2.2 – Outline of Sinkhole Floodplain 9
Figure 2.3 – Karst Terrain Cross-Section 10
Figure 3.1 – Karst Counties of Virginia 13
Figure 3.2 – Valley and Ridge Karst Belt 12

Chapter 1
Introduction

Carbonate bedrock underlies portions of twenty-six counties in western Virginia. The dissolution, or chemical erosion, of carbonate bedrock expresses itself in the formation of landscapes known as karst terrain. Depressions, sinkholes, caves, sinking streams, springs, and underground drainage characterize karst terrain (Kastning & Kastning, 1999). Land development in karst terrain can temporally accelerate and spatially concentrate natural geo-hydrologic processes increasing the risk for several natural hazards including sinkhole subsidence, sinkhole flooding, and ground water contamination.

Although rarely fatal to humans, these natural hazards damage private property and community infrastructure and threaten human health. Urbanization increases the natural hazard risks posed by karst terrains. Kemmerly (1993) asserts that “future [karst natural hazard] losses will increase substantially unless planners recognize risks posed by [karst terrains] and incorporate geologically and hydrologically sensitive guidelines into approval procedures for residential, commercial, and industrial development” (p. 221).

A recent survey of local governments, conducted for the Cave Conservancy of the Virginias by the Urban Affairs and Planning Department at Virginia Tech (Cave Conservancy of the Virginias, 2003), indicates that few communities in western Virginia have adopted land use planning and management tools to minimize karst terrain hazard risks. Populous counties that face rapid urbanization, including Loudoun and Clarke counties, have developed the most comprehensive approaches. Both of these counties address karst terrain in their comprehensive plans, zoning ordinances, and subdivision ordinances. Loudoun and Clarke counties also enhance state and local regulations and policies for septic systems, water supply protection, and stormwater and erosion and sediment control management to better address karst concerns. Although few rural counties use the comprehensive approaches characterized by Loudoun and Clarke counties, concern and demand for better planning and management of development on karst terrains is increasing (Giles County, 2002; Highland County, 2002-2003).

This paper describes why and how local hazard mitigation planning effectively addresses potential natural hazards resulting from development on karst terrain. The paper describes new federal requirements for state and local hazard mitigation planning. The author introduces the three most common natural hazards associated with karst terrain including sinkhole subsidence, sinkhole flooding, and groundwater contamination. A summary of the recently completed Karst Protection Survey demonstrates the current extent of karst hazard planning in Virginia and describes several land use planning and management techniques used by local governments to mitigate potential karst hazards concerns. The final chapter proposes a karst terrain natural hazard planning process and describes a karst feature buffer and overlay hierarchy model for use in Virginia.

Natural Hazard Mitigation Planning

Natural hazard mitigation planning refers to "any sustained actions taken to reduce or eliminate the long-term risk to human life and property from [natural] hazards" (U.S. Federal Emergency Management Agency, 2002: 8849). "The purpose of mitigation planning is for state and local … governments to identify the natural hazards that impact them, to identify actions and activities to reduce any losses from those hazards, and to establish a coordinated process to implement the plan, taking advantage of a wide range of resources" (U.S. Federal Emergency Management Agency, 2002: 8848). New federal guidelines for post-disaster assistance require that state and local governments assess "the type, location, and extent of all natural hazards that can affect the jurisdiction (U.S. Federal Emergency Management Agency, 2002: 8851). The Federal Emergency Management Agency (FEMA) describes a four-phase natural hazard mitigation planning process that includes (1) resources organization, (2) risk analysis and vulnerability assessment, (3) the development of mitigation strategies as part of a mitigation plan, (4) implementation and monitoring of the mitigation plan (U.S. Federal Emergency Management Agency, 2002).

When developing hazard mitigation plans, communities need to recognize that human and economic losses due to natural hazards stem not from unexpected events, but rather the predictable outcomes of interactions among three major systems: the physical environment, the social and demographic characteristics of impacted communities, and the built environment of these communities (Mileti, 1999). Over the past fifty years, the federal government responded to natural hazards largely through structural approaches, like the construction of levees and dams, and by providing disaster relief to communities after a natural disaster. This approach failed to reduce natural hazard expenses. This failure led to the current emphasis on state and local disaster mitigation planning as a primary approach for addressing natural hazards.

What is a natural hazard?

Although often thought of as "Acts of God", natural hazards result from the introduction of human activity and natural processes and events. Natural hazards "are not natural at all, but rather human-made disasters [events] – the result being less of the extreme natural event itself, than that of the inappropriate way we have designed and built our communities and buildings in the hazard-prone areas where they occur" (Geis, 2000: 151). "Thus, despite the convenience of the term, truly 'natural' hazards do not exist" (Smith, 2001: 11).

Each community faces a unique set of actual and perceived natural hazards. The term hazard refers to a "naturally occurring or human-induced process, or event, with the potential to create loss" (Smith, 2001, p. 6), or "a source of danger" (FEMA, 2001). Risk "is the actual exposure of something of human value to a hazard" (Smith, 2001: 6) or "the possibility of loss or injury" (FEMA, 2001). Two primary factors, physical exposure and human vulnerability, determine the level of risk a hazard poses to a community. Physical exposure "reflects the range of potentially damaging events and their statistical variability at a particular location" (Smith, 2001: 12). Human vulnerability "reflects the breadth of social and economic tolerance to such hazardous events at the site" (Smith, 2001: 12). Figure 1.1 displays the interconnected nature of hazards, physical exposure, and human vulnerability that result in the unique risks faced by each community.

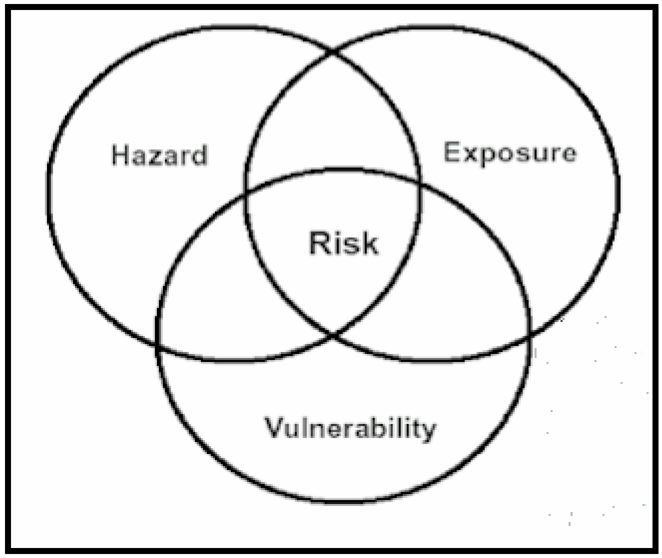


Figure 1.1 – Risk diagram. Source: Randolph (2002)

FEMA categorizes natural hazard events by the conditions that cause them, including atmospheric (hurricanes, tornadoes, blizzards), hydrologic (flooding, coastal storm surges, drought), geologic (earthquakes, landslides), and "other" (dam failure, wildfire, other events caused by human activity) (FEMA, 1997). FEMA concentrates the majority of its efforts on acute natural hazards like floods, earthquakes, tsunamis, hurricanes, tornados, landslide, and wildfires. The rapid-onset of acute natural hazards results in damaging processes or events that produce characteristic threats to human life or well-being. The location of people and property in hazardous areas increases involuntary exposure to acute natural hazards (Smith, 2001).

Some natural hazards produce chronic, rather than acute, impacts. Relatively long-term processes or events, often of obscure origin and consequences characterize chronic natural hazards. These hazards produce effects less concentrated in time and space than acute natural hazards. Chronic natural hazards include water, air, and soil pollution, the spread of disease carrying insects (e.g., the spread of West Nile Virus through mosquitoes); coastal erosion (Smith, 2001); and hazards related to karst terrain. Chronic natural hazards resulting from development on karst terrain include structural damage to both private and public buildings (cracked foundations and walls, building collapse, sinkhole flooding damage); increased maintenance costs for infrastructure (sinkhole collapse in roads, pollution of public drinking water sources); pollution of private drinking water sources; and, the compromising of the health of residents by unrecognized contaminants in drinking water (fecal coliform, *E. Coli*, nitrates, other pollutants carried in stormwater runoff). These hazards rarely result in human fatalities. However, regular investment of a community's limited economic resources to address minor, but constant, consequences of chronic natural hazards effectively reduces the quality of life in a community.

Federal Guidelines for Natural Hazard Mitigation Planning

"Over the past 12 years, federal disaster assistance costs have totaled more than $39 billion, a nearly five-fold increase over the previous 12 year period" (General Accounting Office, 2002: 1). During the last half of this 12-year period, Project Impact, FEMA's pre-disaster mitigation program, provided $77 million to state and local governments for pre-disaster hazard mitigation activities. State and local governments used Project Impact funding to (1) develop partnerships to address mitigation needs; (2) provide "seed money" to attract additional private and public mitigation funds, and (3) heighten mitigation awareness through education and outreach efforts (General Accounting Office, 2002). Participants in Project Impact deem the program "very successful in creating partnerships that identify, and in most cases fund, mitigation activities" (General Accounting Office, 2002: 10).

In an effort to slow increasing natural hazard expenditures and in response to the successes achieved through FEMA's Project Impact, the federal government now strongly encourages pre- and post-disaster hazard mitigation planning for state and local governments. Section 322 of the Robert T. Stafford Disaster Emergency Assistance Act (42 U.S.C. 5165), enacted by Section 104 of the Disaster Mitigation Act of 2000 (P.L. 106-390) [herein after "Section 322"], "provides a significant opportunity to reduce the Nation's [natural hazard] disaster losses through mitigation planning" (Federal Emergency Management Agency, 2002: 8844). Compliance with the requirements of Section 322 determines state and local eligibility for pre- and post-disaster federal funding provided through the Hazard Mitigation Grant Program (HMGP), a post-disaster program that provides funding to communities that have experienced a federally declared natural disaster (General Accounting Office, 2002). HMGP funds support "brick and mortar" projects such as retrofitting structures or relocating building and infrastructure from hazard prone areas (General Accounting Office, 2002).

Section 322 requires a State Mitigation Plan as a condition for HMGP funds; provides additional HMGP funds for states that adopt Enhanced State Mitigation Plans; requires local mitigation plans; and authorizes up to 7 percent of the HMGP funds available to a state for use in the development of state, tribal, and local hazard mitigation plans (Federal Emergency Management Agency, 2002). State and local government must develop and adopt FEMA approved hazard mitigation plans by November 1, 2004 to qualify for HMGP funding after this date (Federal Emergency Management Agency, 2002b).

The *Virginia Hazard Mitigation Plan* designates seven high priority mitigation strategies for the state to pursue over the next five years (2001-2006).

1. "Make available to local jurisdictions information about programs and funding mechanisms that may support mitigation projects;
2. Foster local pre-disaster mitigation planning;
3. Identify existing and potential mitigation projects; seek funding; support post-disaster repairs;
4. Increase public education and awareness of hazards and mitigation;
5. Mitigate damage and losses at local public buildings, school buildings, and water/wastewater treatment facilities and strengthen ability to continue service;

6. Examine measures to help reduce power outages during disasters;
7. Protect state investments in high risk areas" (Virginia Department of Emergency Management, 2001).

The Virginia Department of Emergency Management and the state mitigation plan strongly encourage local governments to develop their own natural hazard plans. Local government involvement strengthens support for the creation of disaster resistant communities, plays an important role in community education about local natural hazards, and allows for innovative approaches to local natural hazard mitigation planning (Virginia Department of Emergency Management, 2001).

The local hazard mitigation plan represents "of the jurisdiction's commitment to reduce risks from natural hazards, [and serves] as a guide for decision makers as they commit resources to reducing the effects of natural hazards" (Federal Emergency Management Agency, 2002: 8851). A committee of community stakeholders, government agencies, and private and non-profit organizations guides the development of the local hazard plan which consists of (1) a statement of guiding principles and goals; (2) a review of local land uses and a history of natural hazard events; (3) a description of all natural hazards found in the community; (4) a discussion of specific hazard mitigation measures the community is committing to; (5) an outline of how at-risk areas will be planned and managed for in the next 10 to 20 years; (6) a description of the management and enforcement processes used to implement mitigation measures; and, (7) a discussion of how to monitor the plan's success and how to update it when appropriate (Federal Emergency Management Agency, 2002).

Mitigation strategies provide "a blueprint for reducing the potential losses identified in the risk assessment, based on [a jurisdiction's] existing authorities, policies, programs and resources, and its ability to expand on and improve these existing tools" (Federal Emergency Management Agency, 2002: 8851). Categories of common hazard mitigation strategies include (1) prevention, (2) property protection, (3) public education and awareness, (4) natural resource protection, (5) emergency services, and (6) structural projects (Federal Emergency Management Agency, 2002).

The hazard mitigation plan includes all applicable and feasible mitigation strategies in a mitigation strategy "wish list". The "wish list" guides the development and implementation of local hazard mitigation activities including public education, partnership building, and policy and ordinance adoption and funding. A community's mitigation strategy "wish list" also helps guide the allocation of state and federal funding and technical assistance when available.

FEMA requires that local governments incorporate the requirements of the mitigation plan into other planning mechanisms such as the comprehensive or capital improvement plans (Federal Emergency Management Agency, 2002: 8851). Inclusion of the hazard mitigation plan in the comprehensive plan facilitates the integration of mitigation goals and programs with other ongoing community goals and programs.

Conclusion

Increasing natural hazards expenditures over the last several decades led to in the federal government's current emphasis on natural hazard mitigation planning. Hazard mitigation planning helps communities minimize exposure to natural hazards through pro-active land use planning and management. Section 322 of the Robert T. Stafford Act requires state and local governments to develop natural hazards mitigation plans for all natural hazards within each jurisdiction.

State and local governments will and should devote a majority of their hazard planning efforts to potentially catastrophic natural hazards like flooding, winter storms, high wind events, and wildfires. In western Virginia, karst terrain produces several natural hazards that local governments need to address in local hazard mitigation plans. Although karst terrain hazards are unlikely candidates for federal and state hazard mitigation funding, numerous land use planning and management options are available to local governments to regulate development on hazardous karst terrain.

Full compliance with the letter and spirit of Section 322 requires local governments to consider and address all natural hazards present within their jurisdictions. This requirement provides local governments with an opportunity to rectify the current paucity of land use planning and management for karst terrain natural hazards in western Virginia. The following chapter describes the three most common karst terrain hazards local governments need to develop hazard mitigation strategies for including sinkhole subsidence, sinkhole flooding, and groundwater contamination.

Chapter 2
Karst Terrain Natural Hazards

Introduction

The term karst refers to "any terrain in which carbonate bedrock (limestone and/or dolomite and/or chalk) is exposed (cropping out), is present beneath soil and/or regolith, and/or may be partially or totally capped by other sedimentary rock. Sinkholes, springs, caves integrated conduits (dissolutionally-enlarged joints (fissures) and/or bedding planes) may be present in carbonate terrain but they may not be obvious. The presence at the ground surface of one, some, or all of these features is not necessary for a carbonate terrain to be defined as karst" (Quinlan *et al*, 1995: 525). Karst features including sinkholes, fractured bedrock, sinking streams, and sinkhole ponds are direct groundwater recharge features that provide little if any contaminant removal benefit to polluted surface waters recharging karst aquifers. Ground water flows rapidly through karst aquifers, via enlarged solution channels, discharging from numerous springs and supplying base flow to surface streams and rivers.

Communities in karst areas must contend with several hydrological/geological natural hazards including sinkhole subsidence, sinkhole flooding, and groundwater contamination (referred to as karst terrain hazards in the remainder of this paper). Karst terrain hazards are unlike other natural hazards in that they are largely chronic in nature and rarely fatal to human beings. Rather than devastating natural disasters, karst hazards result in unnecessary long-term economic burdens on individual property owners and communities.

Sinkhole Subsidence

A sinkhole is "a localized land subsidence, generally a funnel-shaped or steep-sided depression, caused by the dissolution of underlying carbonate rocks [like limestone and dolomite] or the subsidence of the land surface into a subterranean passage, cavity, or cave. Sinkholes are formed by the underground removal of soil and rock material" (North Jersey, undated). An obvious drainage point or "throat," through which concentrated surface waters can flow directly to the subsurface drainage system, may or may not be obvious (Hubbard, 1988).

Sinkhole subsidence results from natural geologic processes that generate differential settling of surface materials. "Virtually any site overlying carbonate rocks, where depth to bedrock is greater than the depth to the water table, poses a potential for subsidence if there are significant fluctuations of the water table" (Hubbard, 1988: no page numbers). "Settling and subsidence results from various mechanisms that are continuously active in karst terrains including compaction due to loading, compaction due to dewatering, settling as materials are removed by groundwater flow, stopping or raveling of materials into void space, and instantaneous collapse into void space" (Hubbard, 1988: no page numbers). Land uses that affect local water tables, including groundwater pumping, the modification of natural drainage patterns, and inappropriate stormwater management drastically accelerate and spatially concentrate sinkhole subsidence. In addition, blasting, vibrations, and/or excess weight above a solution cavern result in sinkhole subsidence by changing subsurface drainage (Southwest Florida Water Management District, undated).

Sinkhole subsidence in developed areas cause costly damage to private property and community infrastructure and occasionally threatens human lives. Sinkholes regularly form along the I-81 corridor in Virginia. In March 2001, the sudden appearance of three sinkholes closed a nine-mile stretch of Interstate 81 in Augusta County. The largest of the sinkholes measured 20-feet long, 11-feet wide, and 22-feet deep – enough to bury eight cars (VDOT, 2001). In 1992, a Clarke County, Virginia home collapsed into a sinkhole that formed underneath its basement soon after drilling a new well on the property, Figure 2.1 (U.S. Geological Survey, 2002). Sinkhole subsidence in the Lehigh Valley of Pennsylvania results in structural damage to buildings, highway subsidence, and disruption of utility lines at an annual cost of $1 million (Dougherty, 1989). Improper stormwater management resulted in a series of sinkholes opening throughout the Borough of Palmyra, Pennsylvania. Between 1991 and 1993, the sinkhole repair bill for just eight of the Borough's many sinkholes reached nearly $900,000, not including the costs of homes destroyed by the sinkholes (Kochanov, 1995).

Figure 2.1 – Clarke County sinkhole
Source: U.S. Geological Survey, 2002

Sinkhole Flooding

Sinkhole flooding in karst terrain forms part of the natural karst hydrologic system. "Flooding occurs during periods of intense rainfall, usually of short duration: (1) when the quantity of stormwater runoff flowing into sinkholes exceeds their outlet capacities, and they cannot drain into underlying caves fast enough to prevent ponding, (2) when the capacity of the cave system to transmit storm water is exceeded, and the water must be stored temporarily in sinkholes since it cannot be stored on floodplains like surface streams, and (3) when a high water table results from a backwater effect on ground water flow caused by surface and subsurface streams at flood stage" (Crawford, 1984, p.283).

Like rivers and streams, sinkhole floodplains store floodwater until the natural drainage system accepts the excess runoff. However, many land planners and local governments fail to recognize sinkhole flooding and sinkhole floodplains because they do not occur along obvious flood prone areas like perennial stream courses (Kemmerly, 1993). In addition, landowners and land planners often underestimate the actual extent of sinkhole floodplains.

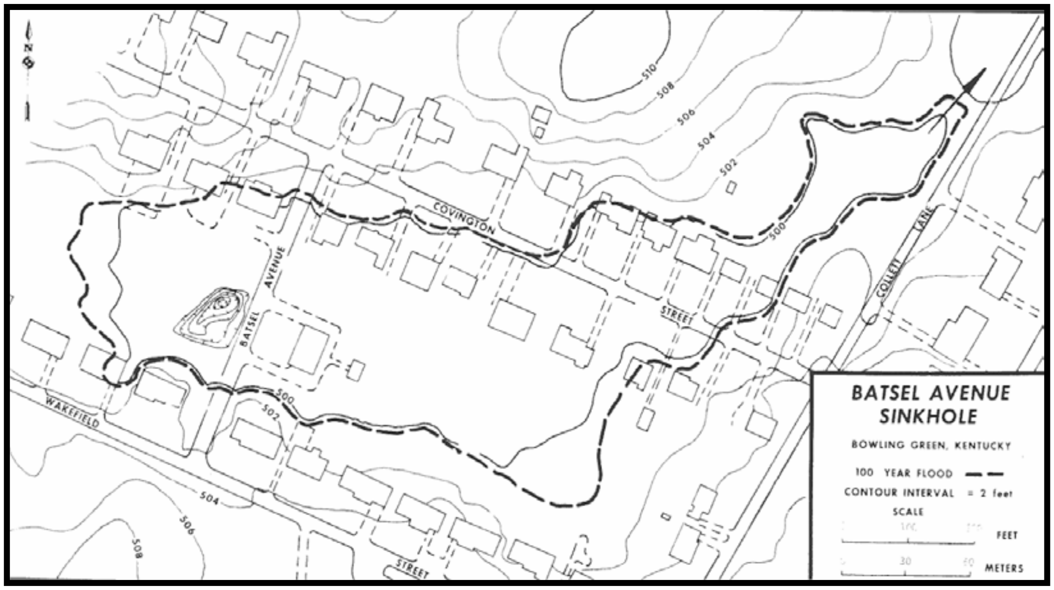


Figure 2.2– Outline of Sinkhole Floodplain
Source: Crawford, 1982: 11

Figure 2.2 illustrates why many communities underestimate sinkhole floodplains. The series of closely spaced contour lines to the west of Batsel Avenue indicates the location of the Batsel Avenue sinkhole. The heavy black dashed line indicates the 100-year sinkhole floodplain for the Batsel Avenue sinkhole. Although land development avoids the actual sinkhole, the community drastically underestimates the extent of the 100-year floodplain. At least sixteen structures and two roads lie wholly or partially within the substantial area delineated by the boundary of the 100-year sinkhole floodplain.

Urban development exacerbates sinkhole flooding. Changes in the natural drainage patterns of the landscape, increases in the quantities and velocities of stormwater runoff due to increased impervious surface, and the clogging of sinkhole throats by eroded sediment, debris, and/or trash increase the extent and frequency of sinkhole flooding in urban areas (Crawford, 1984). The cities of Bowling Green, Kentucky (Crawford, 1984), and Johnson City, Tennessee (Reese, 1997) both suffer major sinkhole flooding problems that force them to designate no-build-areas below sinkhole floodplain elevations to minimize flooding damage. By prohibiting development in sinkhole floodplains, urban and rural communities minimize structural damage to buildings and community infrastructure and help limit groundwater contamination.

Groundwater Contamination

Karst aquifers efficiently and rapidly convey large quantities of water throughout karst areas. Recharge areas, including sinkholes and sinking creeks, provide direct access for surface waters entering the groundwater (Kastning & Kastning, 1999). Diffuse groundwater recharge also occurs as surface waters percolate through the soil and into fractures in carbonate bedrock (Kastning, 1989). Solutionally enlarged channels rapidly transport water through karst aquifers.

Karst groundwater returns to the surface through discharge points like springs, seeps, and wells (Kastning & Kastning, 1999). Unfortunately, due to the fractured nature of carbonate bedrock in karst areas, karst aquifers are extremely vulnerable to contamination (U.S. Geological Survey, 2003). The presence of numerous non-filtering, point source, recharge features like sinkholes, solutionally widened flow paths or solution channels, rapid velocities of ground water and contaminants, and often thin overlaying soils characterize karst aquifers (U.S. Geological Survey, 2002). Figure 2.3 illustrates some of the hydro-geological features that make karst aquifers so vulnerable.

Groundwater velocities in karst aquifers are often extreme, ranging from feet to miles per day. These extreme groundwater flow velocities drastically reduce the potential for water-quality improvement that results from sustained water-soil-rock interactions and chemical and microbial breakdown of contaminants (Kastning, 2002). Dye-tracing helps delineate the direction and velocity of subsurface water flow in karst aquifers by "injecting" fluorescent dye into a karst recharge feature, like a sinkhole, and waiting for the dye to reemerge at a discharge feature, like a spring. Dye-tracing in the Clover Hollow karst system in Giles County, Virginia found groundwater flow velocities of over one mile per day (Kastning, 2002).

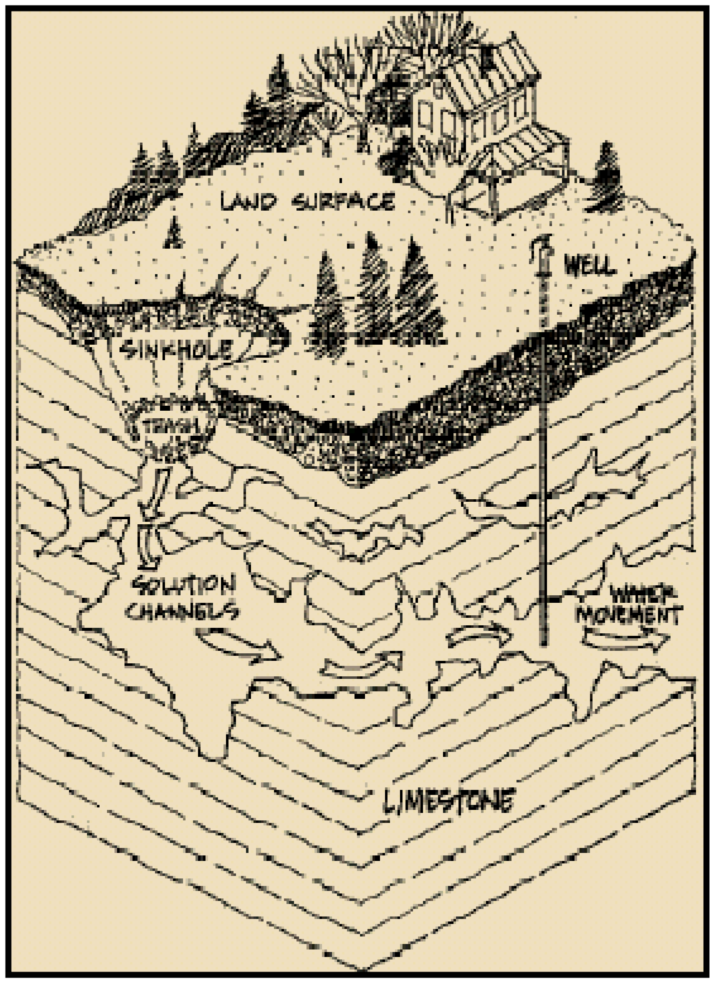


Figure 2.3 – Karst terrain cross-section.
Source: Carpenter, undated.

Sources of groundwater pollution are extensive and include residential, commercial, industrial, agricultural, waste management, and transportation land uses (Virginia Groundwater Protection Steering Committee, 1998; Merideth, 2001). In addition, karst aquifers are vulnerable to the long list of pollution sources that threaten surface water quality because of the direct connection between surface and subsurface water provided by karst features like sinkholes and sinking creeks.

Specific contamination hazards that threaten karst aquifers include, but are not limited to, bacteria in manure (Pasquarell & Boyer, 1995), bio-solids, pesticides (Hallber, *et al,* 1985), fertilizers used in agriculture (Hallberg, *et al,* 1985; Boyer & Pasquarell, 1995), effluent from animal waste lagoons, failing underground storage tanks, hazardous waste spills, runoff from industrial land uses, household chemicals, lawn care products (Kastning & Kastning, 1989), and the numerous pollutants carried in stormwater runoff (Kochanov, 1995). Septic systems, incorrectly or too densely installed or poorly maintained, form a particular concern for groundwater contamination in karst terrains (Panno, *et al,* 1997; Barner, 1997; Kozar, 2001). Illegal sinkhole trash dumps are common sources of groundwater contamination in many karst regions. Some counties in Virginia have hundreds of illegal dumps contaminating local karst aquifers (Slifer and Erchul, 1989).

Conclusion

Development on karst terrain exposes communities to several chronic natural hazards. Sinkhole subsidence and sinkhole flooding damage private property and community infrastructure. Contamination of groundwater and surface waters in karst areas threaten human health as well as animal habitat. Land development in karst terrain often intensifies and concentrates karst terrain natural hazards increasing karst hazard risks in the community.

Whether intended or not, local governments set karst natural hazard planning policies when making decisions about zoning and subdivision regulations, sewage management, and stormwater management. The following chapter illustrates the current karst related land use planning and management tools used by local governments in Virginia.

Chapter 3
Karst Related Land Use Planning in Virginia

Introduction

Virginia's most significant karst terrains extend over portions of twenty-six western Virginia counties in the Valley and Ridge Physiographic Province, which is bound on the east by the Blue Ridge Mountains and on the west by the Alleghany Plateaus Physiographic Province in West Virginia and southwest Virginia, Figure 3.1. Virginia's karst is a product of the folded and fractured limestone and dolomite bedrock found throughout the length of the Valley and Ridge Province, which extends from Georgia to New York, Figure 3.2. The eastern section of this kart belt is known as the Great Valley or the Shenandoah Valley in Virginia. The Great Valley is a limestone-dolomite lowland with rolling hills and extensive surface karst features that "contains the most extensive karst and cavern area in the eastern United States" (Davies and LeGrand, 1972: 484).

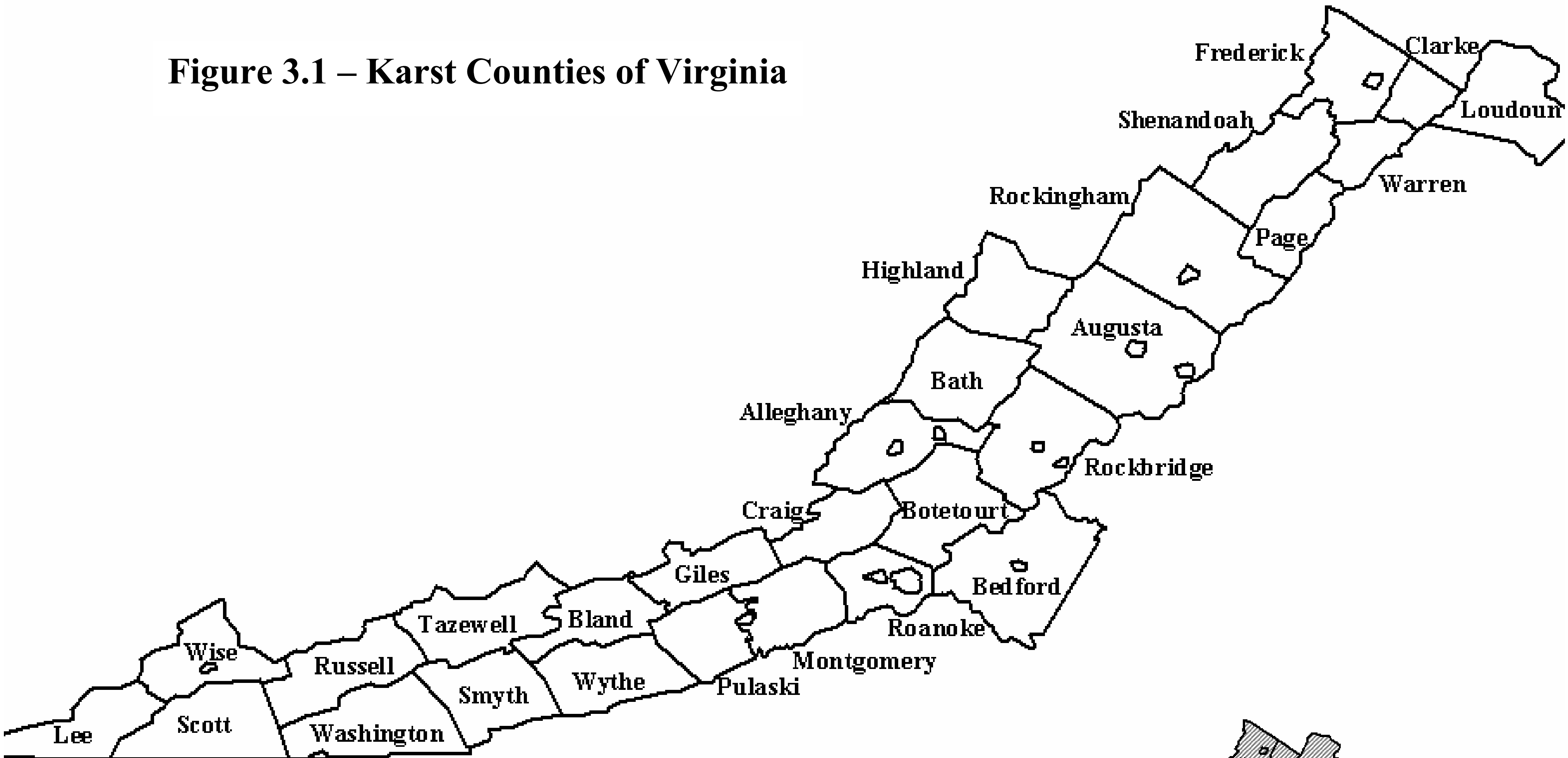
Figure 3.2 – Valley and Ridge Karst Belt
Source: U.S. Geological Survey, 2002

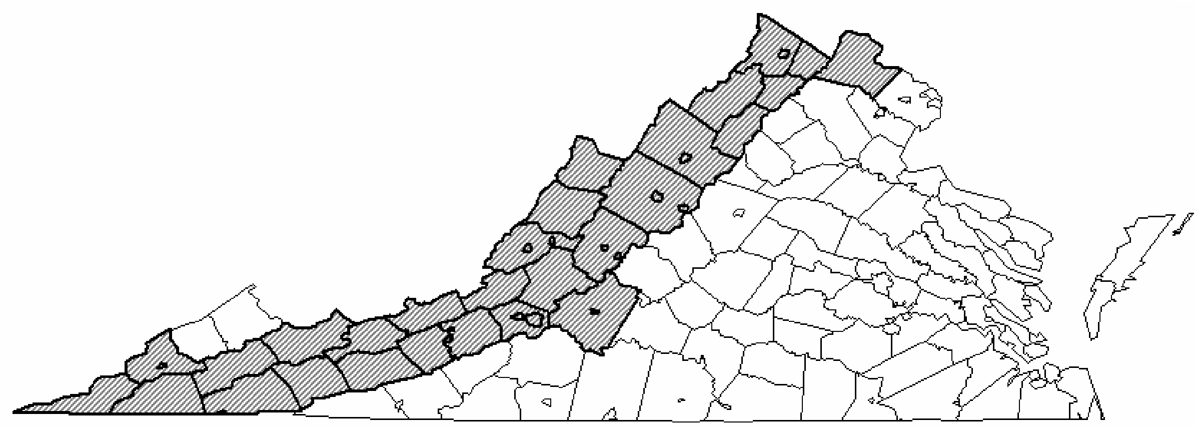
The Virginia Speleological Survey (VSS) (2003) estimates that karst terrain accounts for 20 to 60 percent of county land area in western Virginia, Table 3.1. Using the estimated karst terrain percentages in Table 3.1 and the square mileage of these counties reported by the VSS, the author estimates that western Virginia contains over 4,500 square miles of karst terrain. This area includes at least 48,807 sinkholes[1], ranging in size from 33 feet (10 meters) to 4.2 miles (6.8 kilometers) in length (Hubbard, 2001), over 4,000 caves, 362 of which are "significant caves[2]" (VSS, 2003), nine of Virginia's ten largest springs (VA. Groundwater Steering Committee, 1997), and 130 rare and extremely rare cave species (VA Dept. of Conservation and Recreation, 2003).

[1] The number of sinkholes is likely much greater as this inventory depended heavily on U.S. Geological Survey topo-quads, which are known to misrepresent the actual number of sinkholes on the landscape.

[2] Significant caves are caves with unique, unusual, or significant, biological, geological, historical, or recreational attributes. Significant caves are designated by the Virginia Cave Board (personal discussion with Joey Fagan, Virginia Karst Program, April 10, 2003).

Figure 3.1 – Karst Counties of Virginia





Karst Counties of Virginia (in gray)

Table 3.1 – Estimated karst terrain in Virginia counties. Source: Virginia Speleological Survey, 2003.			
Virginia Counties	**Estimated Karst Terrain**	**Virginia Counties**	**Estimated Karst Terrain**
Alleghany	30%	Page	30%
Augusta	40%	Pulaski	40%
Bath	40%	Roanoke	20%
Bedford	N/A	Rockbridge	40%
Bland	20%	Rockingham	40%
Botetourt	20%	Russell	50%
Clarke	30%	Scott	50%
Craig	30%	Shenandoah	50%
Frederick	30%	Smyth	30%
Giles	50%	Tazewell	40%
Highland	50%	Warren	30%
Lee	60%	Washington	50%
Loudoun	N/A	Wise	20%
Montgomery	40%	Wythe	30%

Karst Protection Survey

A recently completed survey (hereinafter "the Karst Protection Study" or "the Survey") of local governments in western Virginia and eastern West Virginia[3] found that despite an extensive amount of karst terrain few local governments have developed a comprehensive collection of planning and management tools to guide land use development on karst terrains. The survey, conducted by the Department of Urban Affairs and Planning at Virginia Tech and funded by the Cave Conservancy of the Virginias, achieved a 92 percent response rate in Virginia. Table 3.2 summarizes the responses of the twenty-six counties, twelve cities, and twelve towns, that indicated whether or not they reference karst, sinkholes, and/or groundwater in several commonly used land use planning tools including the comprehensive plan, zoning ordinance, and subdivision ordinance. The respondents provided copies of any applicable ordinance or policy for qualitative analysis by the researchers.

Although 54 percent (27) of Survey respondents reference karst, sinkholes, and/or groundwater in local comprehensive plans, less than 15 percent of respondents include similar references in local zoning and subdivision ordinances. Ten percent or fewer respondents reference karst, sinkholes, and/or groundwater in stormwater management regulations, enhanced septic system regulations, and/or water supply protection ordinances. The survey responses indicate that only Clarke County and Loudoun County use a comprehensive set of land use planning tools to guide development in karst areas. The following discussion reviews the major land use planning

[3] West Virginia survey data will not be discussed in this paper.

findings of the Karst Protection Survey to illustrate the current extent of karst hazard planning in Virginia.

Karst Terrain Mapping and Geographic Information Systems

Thirty-six percent (18) of the Survey's respondents indicate that they have maps or geographic information systems (GIS) spatial data for karst features. Several communities include sinkhole, cave, and/or spring maps in their comprehensive plans.

Many jurisdictions identify karst features using 7-1/2 minute U.S.G.S. topographic maps (map scale of 1:24,000 and a contour interval of 20-feet) and/or Natural Resource Conservation Service county soil surveys (map scales generally range from 1:12,000 to 1:63,360 (Natural Resources Conservation Service, 2003)). Both of these map scales prove too large to correctly identify many karst features present on the landscape. For example, a 20-foot contour interval U.S.G.S. topographic map will omit a sinkhole 12 feet deep and tens of feet in diameter unless it happens to intersect one of the 20-foot contour intervals (Kastning & Kastning, 1997). In addition, the topographic map photo-analysis process often fails to recognize certain karst features. For example, topographic maps often designate sinking creeks as dry concave stretches of land, rather than streambeds (personal discussion with Carol Zokaites, Virginia Karst Program, March 11, 2003). The Virginia Department of Conservation and Recreation (undated) estimates that in some parts of Virginia standard 1:24,000 topographic maps show less than 50% of the karst features present on the landscape.

For these reasons, a smaller, more detailed mapping scale is necessary for appropriate consideration of karst terrain hazards on individual parcels of land. Although some communities in the United States require karst features to be mapped at a 1-inch = 100-feet map scale (Dougherty, 1989), Loudoun County requires a 1-inch = 200-feet map scale. The latter map scale is particularly useful because many communities already require other land use planning maps and site plans to conform to this map scale.

Several communities including Clarke County, Loudoun County, Rockbridge County and the Town of Blacksburg use GIS to map karst features for inclusion in comprehensive plan maps. However, creating sinkhole maps for local comprehensive plans underutilizes the vast risk assessment and land use management capabilities of GIS in karst areas. For example, Carroll County, Maryland uses an extensive GIS mapping program, linked to a database management program, to identify local karst features for land use planning, ground water studies, and infrastructure maintenance (Devilbiss, 1995). Several communities in southern Minnesota use GIS to create county sinkhole probability maps, study groundwater contamination in karst lands, and develop maps that identify karst features and interpret karst groundwater flow systems (Gao, *et al,* 2001; Green, *et al,* 2001). The City of San Antonio, Texas uses GIS to prioritize land conservation purchases to protect important groundwater recharge areas in the karstic Edwards Aquifer (Stone, *et al*, 2002).

Table 3.2 – Summary of Karst Protection Survey Findings

Source: Cave Conservancy of the Virginias, 2003.

Note: Survey participants were asked if their jurisdictions referred to karst, sinkholes, or groundwater in several land use planning and management tools.

Virginia Counties	**Alleghany County**	**Augusta County**	**Bath County**	**Bedford County**	**Bland County**	**Botetourt County**	**Clarke County**	**Craig County**	**Frederick County**	**Giles County**	**Highland County**	**Lee County**	**Loudoun County**	**Montgomery County**	**Page County**	**Roanoke County**	**Rockbridge County**	**Rockingham County**	**Russell County**	**Scott County**	**Shenandoah County**	**Smyth County**	**Tazewell County**	**Warren County**	**Washington County**	**Wythe County**
1) Karst mapping (GIS or hardcopy)	X						X		X	X			X	X			X				X			X		
2) Comp plan element	X				X	X	X		X	X	X		X	X	X		X	X		X	D	X		X	X	X
3) Zoning ordinance						X	X		X				X								X					
4) Subdivision ordinance						X	X			X			X								X			X		
5) Stormwater ordinance							X						X													
6) Waste management policies							X						X													
7) Water supply protection policies							X						X													
8) Household & agricultural hazardous waste program									X															X		
9) Enhanced septic system requirements							X						X								X					
10) Karst ordinance developed, but not adopted																	X									
11) Cooperates with other organizations related to karst			X				X		X	X			X				X							X		
12) Other karst related regulations						X	X			X				X			X							X		

Virginia Cities and Towns	**Bedford, City**	**Bristol, City**	**Buena Vista, City**	**Harrisonburg, City**	**Lexington, City**	**Norton, City**	**Radford, City**	**Roanoke, City**	**Salem, City**	**Staunton, City**	**Waynesboro, City**	**Winchester, City**	**Abingdon, Town**	**Blacksburg, Town**	**Bluefield, Town**	**Christiansburg, Town**	**Clifton Forge, Town**	**Front Royal, Town**	**Leesburg, Town**	**Luray, Town**	**Marion, Town**	**Pulaski, Town**	**Tazewell, Town**	**Wytheville, Town**
1) Karst mapping (GIS or hardcopy)				X	X	X				X	X		X	X	X				X					
2) Comp plan element		X			X		X			X	X		X	X		X					X			
3) Zoning ordinance											X													
4) Subdivision ordinance							X																	
5) Stormwater ordinance				X				X							X									
6) Waste management policies																								X
7) Water supply protection policies																					X			
8) Household & agricultural hazardous waste program																								
9) Enhanced septic system requirements													X		X				X					
10) Karst ordinance developed, but not adopted															X									
11) Cooperates with other organizations related to karst							X				X			X	X			X	X			X		
12) Other karst related regulations				X				X							X									

Legend

X – indicates an affirmative response by the local government

D – indicates that the karst reference is in a draft document

Comprehensive Plan

The Virginia Code Section 15.2-2223 requires all jurisdictions in Virginia to adopt a comprehensive plan to direct the future orderly development of the community. The comprehensive plan guides the development and implementation of local zoning and subdivision ordinances, capital improvement programs, and official maps. Virginia communities consider several karst hazard related factors including groundwater, surface water, geology, flood prevention measures, and environmental factors in the preparation and implementation of the comprehensive plan. (Va. Code Sec.15.2-2223 & 15.2-2224). Comprehensive plans are particularly appropriate for planning and managing land uses in hazardous areas like karst terrain. Benefits include:

- Identifying "critical hazard areas" as well as (1) compatible land use activities for those areas; (2) appropriate development and construction standards and practices for future development in such areas; and (3) policies for retrofitting existing development in such areas.
- Identifying areas less vulnerable to hazards, where development and redevelopment will be encouraged and supported.
- Avoiding hazardous areas in siting community facilities and water and sewer and transportation strategies (Godschalk, *et al,* 1998).

Fifty-four percent (27) of the Survey's respondents indicate that their comprehensive plans include an element, map, or chapter addressing or referring to karst, sinkholes, and/or groundwater. However, the majority of these elements consist of no more than a paragraph or sentence defining karst. Most provisions fail to explain the hazards karst terrain pose to land use development.

The comprehensive plan for the Town of Blacksburg, Virginia includes karst features and sensitive karst in its significant open space inventory. Local governments like Blacksburg have several open space preservation techniques available to restrict development on land vulnerable to karst terrain hazards including strategic capital improvements programming and voluntary land use restrictions[4].

Capital Improvements Programming

The capital improvement program (CIP) is the multi-year scheduling of public infrastructure improvements like roads, sewers, waterlines, and schools (Virginia Chapter of the American Planning Association, 2002). The strategic application of the CIP can steer development away from sensitive environmental areas, like karst terrain, by coordinating infrastructure investment

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[4] Although many of these programs seem most applicable to large or multiple karst features and their associated buffers and drainage areas even a single, moderately sized karst feature and its buffer may justify the application of these options. For example, applying a fixed radius, 100-foot buffer from the edge of a 50-foot diameter sinkhole requires land use restrictions on an area totaling over one acre. Assuming the sinkhole is circular, the area of a 125-foot radius circle (25-foot radius for the sinkhole, plus 100-foot radius for the buffer) equals 49,087 square feet, or 1.13 acres.

including sewer, water, and transportation to targeted development areas. Although this technique does not prohibit development in karst terrain, it may discourage both the types of development and the high densities of development that prove most problematic in karst areas.

By programming capital improvements to avoid sensitive karst terrain a community not only reduces the natural hazard risk associated with karst terrain, but also ensures the continued functioning of valuable green infrastructure. Green infrastructure is based on the idea that elements of the natural environment that perform functions that benefit a community are types of infrastructure as essential as the built infrastructure more commonly funded (Beatley, 2000). Green infrastructure functions common in karst terrains include drinking water supply, groundwater recharge, underground drainage and storage of stormwater, open space, animal habitat, and recreation.

One of the largest karst terrain green infrastructure investments occurs in the City of San Antonio, Texas. The city invests tens of millions of dollars to maintain ground water quality by protecting groundwater recharge areas in the karstic Edwards Aquifer from unsuitable land uses (Trust for Public Land, 1998). Since 2000, the city has spent at least $22.5 million for the purchase and permanent protection of 3499 acres (1416 hectares) of land in areas identified as important groundwater recharge areas overlaying the aquifer (Stone, *et al*, 2002).

Voluntary Land Use Restrictions

Applying additional open space preservation techniques further supports the goals of strategic capital improvements programming for high-risk karst areas. Both the donation of conservation easements by private landowners and government purchase of development rights permanently restrict land uses in high-risk karst areas by preserving these areas as open space. Conservation easements are legal agreements between a landowner and a land trust or government agency. The easement permanently restricts development on a parcel of land in order to protect its conservation value.

The purchase of development rights (PDR) involves a local government purchasing the right to develop a property from a landowner. Due to the high expense, local governments are unlikely to depend on the PDR as a primary karst terrain conservation tool. However, the PDR may prove the only way to protect sensitive karst terrain on parcels that can be developed "by-right" in a way that is incompatible with the goals and objectives of a locality's karst terrain hazard mitigation goals and objectives. Landowners utilizing conservation easements and PDR retain all property rights other than the right to develop the property (Virginia Chapter of the American Planning Association, 2002).

The inclusion of high-risk karst areas in agricultural and forest conservation districts and land use assessment taxation programs encourage landowners to temporarily restrict land uses in exchange for property tax benefits. Land use assessment and taxation programs use discounts in property tax assessments to promote and preserve agricultural and forestal land uses and open space, which could include sensitive or hazardous karst areas. Farmers, foresters, and landowners voluntarily enroll their land in agricultural and/or forest conservation districts to conserve rural, forest, and agricultural areas. Local governments can encourage the inclusion of karst terrain in agricultural and forest conservation districts (Virginia Chapter of the American Planning Association, 2002). The application of voluntary open space preservation options restricts land development in high-risk karst areas helping to reduce community exposure to karst natural hazards.

Subdivision Regulation

The Virginia Code requires that every locality adopt subdivision regulations to assure the orderly subdivision of land and its development. The division of land results in more intense and different land uses that have impacts on surrounding land and communities. It provides reasonable regulations and provisions for, among other things, drainage and flood control (Virginia Chapter of American Planning Association, 2002).

The subdivision of land is a "by-right" allowance for landowners. Even if a proposed subdivision is not compatible with current land use planning goals and objectives of the community the local government must accept the subdivision if it complies with the local subdivision regulations. If parcels within hazardous areas are subdivided before natural hazard related land use restrictions are adopted, the only way to prevent their development is for the local government to purchase the parcels (Olshansky, *et al,* 1998). Therefore, subdivision regulations must reflect the community's goals and objectives for managing land use on karst terrain.

Fourteen percent (7) of the Survey's respondents reference karst, sinkholes, or groundwater in their subdivision ordinances. Three communities, including Giles County, limit this reference to the consideration of topographical limitations, including sinkholes, in the subdivision of land. The Loudoun County subdivision ordinance refers to the county's Facilities Standards Manual, which includes three chapters that address karst terrain land use concerns: *Chapter 5: Water Resource Management; Chapter 6: Soils, Geotechnical, and Hydrogeological Review;* and *Chapter 7: Environmental Design Standards.*

Zoning Ordinance

Local governments use a wide assortment of regulatory and non-regulatory options to control, discourage, and prohibit development on karst terrain. One tool is the local zoning ordinance. "A zoning ordinance divides a community into districts, or zones, and regulates land use activity in each district, specifying the permitted uses of land and buildings, [and] the intensity or density of such uses" in order to limit conflict between incompatible land uses (Meck, *et al,* 2000: 343). Originally implemented to limit conflict between incompatible land uses in urban areas, zoning has proven a valuable tool in protecting natural resources.

Twelve percent (6) of the respondents to the Karst Protection Survey reference karst, sinkholes, and/or groundwater in their zoning ordinances. The majority of these communities make minimal reference to karst in their zoning ordinances. However, both Clarke County and Loudoun County employ significant karst related zoning restrictions through local zoning overlay districts.

Karst Related Zoning Overlay Districts

Zoning overlay districts impose additional development standards beyond those applied in the existing zoning districts to address special land use concerns. Overlay districts prove especially effective in protecting environmental resources with indistinct boundaries that do not coincide with established zoning districts (Meck, *et al,* 2000). Clarke County uses a *Spring Conservation Overlay District* (Clarke County Zoning Ordinance, Section 3-E-2) to protect the groundwater recharge area of Prospect Hills Spring, a karstic spring, from contamination by adjacent land uses. The county's *Stream Protection Overlay District* restricts the land application of bio-solids around sinkholes and perennial springs (Clarke County Zoning Ordinance, Section 3-C-1). Loudoun County relies on a comprehensive *Limestone Conglomerate Overlay District* (Loudoun County Land Use Restrictions, Section 4-1900) to manage land uses in areas underlain by limestone bedrock. Many communities outside of Virginia also use overlay districts to address karst hazard concerns (City of Cookeville, TN, undated; East Marlboro Township, PA, 1979; West Whiteland Township, PA, 1984).

Many local governments throughout the United States, including Loudoun County, define the boundaries of the karst overlay district by the extent of underlying carbonate bedrock. Within these boundaries, most local governments commonly apply one or more of three categories of additional land use restrictions including karst feature buffers, geotechnical studies or additional site plan requirements, and additional performance standards (Richardson, 2003).

Karst Feature Buffers

Karst feature buffers restrict land uses around a karst feature in order to maintain vegetation and tree cover within the buffer area. The vegetation and tree cover reduces non-point source pollution from surrounding land uses (Barfield, *et al,* 1998) and provides habitat for animals (Buchsbaum, 1994). The prohibition of most land uses within the karst feature buffers, at least for sinkholes, also helps minimize community exposure to sinkhole subsidence and sinkhole flooding. Both Loudoun County and Clarke County, as well as communities outside of Virginia (Bloomington, IN., 2000), require fixed karst feature buffers extending from the edge of a karst feature. However, delineating buffers to reflect a karst feature's drainage basin helps to identify more accurately the area of land influencing or affected by local karst features (Kastning and Kastning, 1997).

Geotechnical Studies

Loudoun County's zoning overlay district requires a geotechnical study for all development underlain by limestone bedrock. Geotechnical studies determine potential karst natural hazard risks for proposed development sites by identifying the soils, geology, and hydrology both above and below the surface of the site. The geotechnical study usually includes two phases. The first phase involves a preliminary site investigation done prior to site design and development. The second phase requires a site-specific investigation (Department of Conservation and Recreation, undated).

Geotechnical studies allow planning staffs and property owners to implement project-specific design and engineering approaches that can mitigate, to the maximum extent possible, potential karst terrain hazards on the property. Geotechnical studies also help determine how to most efficiently meet performance standard requirements for stormwater runoff, septic systems, and wellhead and spring protection.

Performance Standards

Performance standards require land uses to achieve declared goals and objectives but do not mandate specific actions that development must take. Many performance standards in karst areas help maintain pre-development stormwater runoff quantity and quality through stormwater management and erosion and sediment control efforts. Performance standards related to private septic systems and spring and wellhead protection ensure the quality of groundwater drinking sources in karst terrain.

Participants in the Karst Protection Survey indicated whether their jurisdictions require karst related performance standards for stormwater management, septic system, and groundwater protection. Less than 10 percent (6) of the respondents have stormwater management regulations that reference karst. The majority of these respondents had adopted Virginia Stormwater Management Regulations. Ten percent (6) of Survey respondents utilize enhanced septic system regulations to better protect groundwater in karst terrain. Only three jurisdictions consider karst in local water supply protection ordinances, regulations, or policies.

Stormwater Management and Erosion and Sediment Control

Karst terrain provides a natural subsurface drainage system for landscapes overlaying carbonate bedrock. However, concentrations of post-development stormwater runoff can destabilize the natural karst geo-hydrologic system leading to rapid sinkhole development, sinkhole flooding, and groundwater contamination. Ten percent (5) of the respondents to the Karst Protection Survey reference karst in their stormwater management regulations.

The "principal approach for alleviating erosion, sedimentation, and flooding problems in karst is to maintain rates of recharge and discharge in the subsurface at the desired natural levels" (Kastning 1994: 6). The "desired natural levels" refers to the predevelopment recharge and discharge rates. State developed stormwater management and erosion and sediment control regulations help maintain desired natural levels for recharge and discharge in karst areas.

Virginia law enables all jurisdictions to adopt the Virginia Stormwater Management Regulations (4VAC 3-20 2001) developed by the Department of Conservation and Recreation. An addendum to the Virginia Stormwater Management Handbook, entitled Technical Bulletin No. 2: Hydrologic Modeling and Design in Karst, addresses some of the unique stormwater management concerns common to karst areas. A series of work-group meetings hosted by the Virginia Karst Program brings together a wide assortment of karst and stormwater stakeholders to develop additional karst specific addendums for inclusion in the Virginia Stormwater Management Handbook.

Effective enforcement of the Virginia Erosion and Sediment Control Regulations (ESCR) (4VAC50-30 2001) reduces sediment erosion that clogs sinkholes leading to flooding, sinkhole collapse and ground water contamination. Minimum Standard-19 of the ESCR requires that properties and waterways downstream from development sites be protected from sediment deposition, erosion, and damage due to increases in volume, velocity, and peak flow rate of stormwater runoff for the stated frequency storm of 24-hour duration. This requirement applies to all state waters, including those wholly or partially underground, i.e., karst aquifers. By carefully managing stormwater and sediment erosion resulting from urban land uses, communities limit the extent and intensity of sinkhole subsidence and sinkhole flooding, the most costly karst related natural hazards.

Water Supply Protection Policies

Only three jurisdictions participating in the Karst Protection Survey use karst related water supply protection policies. Clarke County utilizes the most extensive set of land use policies and ordinances to protect drinking water supplies. The county's *Groundwater Resources Plan,* (Article 5a of the *Clarke County Comprehensive Plan Implementing Component*) provides a comprehensive overview of groundwater concerns in the county and provides an extensive list of actions the county should take to further protect groundwater. A sinkhole ordinance (Chapter 180, Article 2, Section 180.6-180.12) establishes land use controls to minimize the movement of pollutants through sinkholes into subsurface waters. Clarke County includes karst water supply protection efforts in its zoning ordinance and in a wellhead protection ordinance.

Spring and wellhead protection ordinances assess and manage land uses near springs and public water supply wells in order to prevent ground water contamination by safeguarding spring and wellhead capture zones. Capture zones delineate groundwater recharge areas that contribute water to the aquifer from which a spring or well is drawing its water. Communities often use arbitrarily set radii to delineate multiple land use restriction zones centered on public-water system wells or springs in order to protect the water source's capture zones or recharge areas (U.S. Environmental Protection Agency, 2002).

In Virginia, communities delineate two zones around each groundwater public water supply. Zone 1 includes all land within a 1000-foot radius from the wellhead. Within Zone 1, local governments identify land use activities and potential conduits to groundwater. Zone 2 includes all land within a 1-mile radius around each ground water drinking source. Local governments use available GIS data to identify sites of potential groundwater contamination in Zone 2 (Virginia Department of Health, 1999). Unfortunately, "the fixed-radius approach has significant deficiencies that are particularly troubling in karst settings. The approach is flawed by the assumption that water flows equally from all directions, and can significantly underestimate wellhead and spring capture zones. This is a particular problem in karst, because of its high vulnerability to contamination, high ground-water velocities and limited opportunity for in-situ remediation" (U.S. Environmental Protection Agency, 2002).

Local governments attempting to more accurately estimate capture zones for springs and public-water supply wells in karst aquifers use several relatively expensive and time-consuming techniques. The most commonly used techniques include (1) approximating the spring capture zone from the distribution of karst recharge features, (2) approximating ground water drainage basins using well measurements, and (3) conducting dye-tracings, the most reliable technique if there are an adequate number of karst recharge features (U.S. Environmental Protection Agency, 2002).

The U.S. EPA recently published *Delineation of Source-water Protection Areas in Karst Aquifers of the Ridge and Valley and Appalachian Plateaus Physiographic Provinces: Rules of Thumb for Estimating the Capture Zones of Springs and Wells* (2002). This document provides cost effective techniques for approximating spring and well capture zones in Appalachian karst aquifers. These techniques more accurately delineate karst capture zones than the fixed-radius method and incur less cost than other available methods. The "rules of thumb" guide technical professionals implementing either Wellhead Protection Programs or Source Water Assessment and Protection Programs, or those who are interested in supporting the goals of these programs (U.S. Environmental Protection Agency, 2002).

Enhanced Septic System Regulations

Karst areas present extreme risk of groundwater contamination due to failing septic systems. Many communities enhance state septic system regulations to better protect groundwater in karst areas. In Virginia, the state's *Sewage Handling and Disposal Regulations* (2000) provide minimum standards for the installation of private septic systems. Table 3.3 illustrates some of the enhancements local governments in karst areas have made to the state septic system regulations. The majority of enhancements increase setback minimums between septic systems and the edge of the sinkholes, caves, and springs. Some communities also increase the separation distance from the bottom of septic system drain fields to bedrock, water table, or soil layers with unsatisfactory percolation rates.

Two additional septic system enhancements, required in all Virginia Tidewater counties and cities, include mandatory septic system maintenance every five years and the provision of reserve drain fields equal to 100 percent of the original drain field. Failing septic systems often contaminate groundwater and soil for long periods without a homeowner's knowledge. "Although more than half of the systems in the U.S. fail after 15 to 20 years, the conventional septic system can last for as long as 50 years if the homeowner maintains it properly" (Sevebeck & Kroehler, 1992: 1). By requiring septic system maintenance every five years, local governments help ensure that these systems continue to function properly. In addition, regular maintenance helps identify failing systems that need replacement. Requiring reserve drain fields equal to the size of the original drain field, ensures that failing septic systems, once discovered, are quickly shutdown and replaced limiting potential ground water and soil contamination.

Table 3.3 – Examples of septic system regulation enhancements	
Locality	**Septic system regulations**
Virginia Sewage Handling and Disposal Regulations[1]	♦ 100 foot setback from the ***lowest point*** in the sinkhole when placed with the bowl of a sinkhole; ♦ 100 foot setback from developed springs that are down slope ♦ 12 inch minimum separation from the bottom of the drain field trench to bedrock, water table, or soil layers with unsatisfactory percolation rates.
Clarke County, VA[2]	♦ 100 foot setback from the edge of sinkhole and cave entrances; ♦ 500 foot setback from springs at a lower elevation than the septic system; ♦ 200 foot setback from springs at a higher elevation than the septic system; ♦ 20 inch minimum separation distance from the bottom of the drain field trench to soil layers with unsatisfactory percolation rate and 2 foot minimum separation from bedrock.
Loudoun County, VA[3]	♦ 50 foot setback from the edge of a sinkhole; ♦ 4 foot minimum separation distance from the bottom of the drain field trench to bedrock, water table, or soil layers with unsatisfactory percolation rates.
Shenandoah County, VA[4]	♦ 50 foot setback from the edge of a sinkhole
Warren County, VA[5]	♦ 100 foot setback from the edge of a sinkhole.

[1] Source: Virginia Dept. fo Health (2000). Sewage Handling Disposal Regulations (12 VAC 5-610-10 et seq.)
[2] Source: Clarke County (VA), (2002) Septic System Ordinance, Article 2, Section 143.6-143.13.
[3] Source: Loudoun County (VA), (1997) Land Subdivision and Development Ordinance. Section 1245.10.
[4] Source: Shenandoah County (VA), Zoning Ordinance, Section 165-85.2. On-Site Sewage Disposal Systems.
[5] Source: Warren County (VA), Subdivision Ordinance, Section 179-8, Location of wells.

Other Karst Related Ordinances, Regulations, and Policies

Two communities in the Survey have developed stand-alone karst ordinances. Rockbridge County never adopted its *Ordinance for the Protection of Sinkholes*. Clarke County's sinkhole ordinance (Chap. 180: Water and Wastewater – Article 2) protects subsurface waters from pollution by prohibiting the movement of pollutants through sinkholes. To achieve this goal, the county classifies sinkholes into two categories: Class 1 and Class 2 sinkholes. Class 1 sinkholes present significant subsurface water pollution hazards. Class 2 sinkholes are all sinkholes other than Class 1 sinkholes. This sinkhole classification scheme clarifies the risk and vulnerability related to individual sinkholes to help identify necessary land use restrictions applicable to associated parcels of land. Virginia state agencies use and/or propose the use of two more complex classification schemes, summarized in Table 3.4.

The Virginia Department of Agriculture and Consumer Services (Virginia Groundwater Protection Steering Committee, 1998) uses an elaborate six-category sinkhole classification system to investigate ground water pollution complaints resulting from agricultural activities. This classification system correlates ground water vulnerability with sinkhole drainage rates and the ability of the soil in the bottom of the sinkhole to filter pollutants from surface water entering the sinkhole. Type 5 sinkholes least likely result in groundwater contamination while Class 1 sinkholes provide very likely points of groundwater contamination. A final category indicates sinkholes used as Class Five Injection Wells. Class Five Injection Wells are sinkholes or bedrock fissures modified for stormwater drainage.

The draft *Sinkhole Classification Scheme for Virginia's Karstlands,* developed by the Virginia Karst Program (Orndorff, 2001) provides a more complex sinkhole classification system. This classification system identifies and prioritizes sinkhole vulnerability using six parameters including: (1) sinkhole watershed and hydrologic activity; (2) sinkhole shape and slope characteristics; (3) type of groundcover in the sinkhole; (4) morphology of the sink bottom; (5) drainage of sinkhole; and, (6) relationship to other sinkholes and hydrologic features. Local land use planners determine groundwater contamination susceptibility by combining the sinkhole's vulnerability rank for each of the six parameters.

Conclusion

The Karst Protection Survey indicates that few communities in Virginia use a coordinated, comprehensive approach to manage land uses on karst terrains. While over fifty percent of the counties, cities, and towns in western Virginia reference karst in their comprehensive plans, a much smaller number of communities reference karst in their zoning and subdivision ordinances. An equally small number have adopted stormwater management, enhanced septic system ordinances, and/or water supply protection policies.

In Table 3.5, the author groups the various options used by or available to local governments planning and managing land use in karst terrain into three categories: natural hazard assessment options, regulatory mitigation strategies, and non-regulatory mitigation strategies. Table 3.5 summarizes some of the advantages and disadvantages of the land use planning and management options discussed in this chapter. The inclusion of clear karst terrain land use planning and management goals, objectives and strategies in the comprehensive plan lays the necessary groundwork to make the adoption of regulatory and non-regulatory karst mitigation strategies politically feasible.

Local natural hazard mitigation planning for karst terrain depends on many techniques and tools already pioneered by karst communities. The next chapter presents a hazard planning process that guides local governments through the development of an effective karst terrain natural hazard mitigation plan.

Table 3.4 – Sinkhole Classification Schemes

Sinkhole Ordinance **Clarke County, Virginia**[1]	**Virginia Dept. of Agriculture and Consumer Service**[2]	**Sinkhole Classification Scheme for Virginia's Karstlands (DRAFT)**[3]
Class 1 – "Any sinkhole which presents a significant subsurface water pollution hazard if, due to drainage pattern of the land surrounding the sinkhole or the nature of the substances or objects in the sinkhole, the sinkhole may permit the entry of pollutants into subsurface water." **Class 2 –** "Any sinkhole which is not a Class 1 sinkhole for reasons pertaining to the sinkhole characteristics for transporting pollutants to the subsurface."	**Type 5 -** Soil-covered sinkhole with no obvious sinkpoint. Poorly drained. May pond after rainfalls. May contain water-tolerant plants. **Type 4 -** Soil-covered sinkhole with no obvious sinkpoint. No signs of ponding. Fairly well drained. **Type 3 -** Exposed bedrock sinkhole with no obvious sinkpoint. No signs of ponding. Fairly well drained. **Type 2 -** Soil-covered sinkhole. Obvious sinkpoint. Very well drained. **Type 1 -** Exposed bedrock sinkhole. Obvious sinkpoint. Very well drained. **Class 5 Injection Well -** A sinkhole, crack, or fissure that has been modified or improved by man to allow efficient drainage of surface water.	**A. Watershed and hydrologic activity** 1. hydrologically isolated sinkhole 2. non-receiving connected sinkhole 3. swale receiving sinkhole 4. intermittent receiving sinkhole 5. perennial receiving sinkhole 6. internal spring receiving **B. Shape slope characteristics** 1. shallow 2. intermediate slope 3. steep sided 4. vertical sided **C. Groundcover in sink** 1. nature of vegetation 2. exposure of subsurface material **D. Morphology of sink bottom** 1. flat bottomed 2. tapered bottom 3. open throated 4. compound **E. Drainage of sinkhole** 1. well drained 2. poorly drained 3. ponded 4. surging sinkhole **F. Relationship to other sinkholes and hydrologic features** 1. isolated 2. cluster 3. belt

[1] Source: Clark County, Virginia (1988). Chapter 180 – Water and Wastewater, Article 2, Sinkholes (180-6 to 180-12).
[2] Source: Groundwater Protection Steering Committee (1998). *1998: Ground Water Protection in Virginia Eleventh Annual Report of the Ground Water Protection Steering Committee.* Virginia Department of Environmental Quality.
[3] Source: Orndorff, W. (2001). *A Sinkhole Classification Scheme for Virginia's Karstlands (DRAFT).* Virginia Department of Conservation and Recreation, Division of Natural Heritage, Virginia Karst Program.

Table 3.5 – Summary of Planning Options for Managing Land Uses in Karst Terrains		
Planning Options	**Advantages**	**Disadvantages**
Hazard Assessment Options		
Karst classification scheme	- Improves identification of risk associated with individual karst features - More accurate targeting of land use restrictions to high risk areas	- Complex schemes may be difficult to develop - Requires extensive training for correct interpretation of complex classification schemes
Geographic information systems	- Mapping and database capabilities - Already in use by many land use planning departments	- Karst terrain spatial data may be hard to establish
Improved mapping techniques	- Improves comprehensiveness of local karst feature inventory	- Requires additional staff-time, and funding
Regulatory Mitigation Strategy Options		
Karst overlay zoning district	- Applies land use restrictions based on karst terrain boundaries	- Overlay district boundaries may be ambiguous
Karst feature buffers	- Reduces community exposure to karst hazards - Minimizes non-point source pollution entering groundwater through sinkholes - Provides animal habitat	- Buffer areas may make extensive amounts of private property unusable - Buffer areas may be difficult to delineate
Geotechnical studies	- Accurately identifies karst hazards for individual parcels of land	- May be prohibitively expensive for individual land owners
Enhanced septic system regulations	- Ensures long-term, effective functioning of septic systems - Protects groundwater and surface water quality - Extends life septic system equipment	- May be expensive for local governments to monitor - May burden land owners with expensive septic system repair bills
Stormwater management regulations	- Maintains pre-development stormwater runoff quantity and quality	- May be prohibitively expensive to implement and enforce
Erosion and sediment control regulations	- Limits clogging of karst terrain recharge features	- May be prohibitively expensive to implement and enforce
Spring and wellhead protection policies	- Protects groundwater recharge areas to protect drinking water	- May be prohibitively expensive to implement and enforce
Non-Regulatory Mitigation Strategy Options		
Capital improvements program	- Steers development dependant on community infrastructure away from sensitive karst terrain	- Does not prohibit development in sensitive karst terrain
Conservation easements	- Provides permanent protection for karst features and associated buffer areas	- Requires land owner initiative and voluntary compliance
Purchase of development rights	- Provides permanent protection for karst features and associated buffer areas	- May prove too expensive for many local governments
Agricultural and forestal districts	- Encourages voluntary land uses restrictions around high-risk karst features	- Requires land owner initiative and voluntary compliance - Does not permanently restrict land uses in karst terrain
Land use assessment and taxation programs	- Encourages voluntary land uses restrictions around high-risk karst features	- Does not permanently restrict land uses in karst terrain

Chapter 4
A Process for Karst Hazard Mitigation Planning in Virginia

Introduction

The natural hazard mitigation planning requirements of Section 322 of the Robert T. Stafford Act provide an opportunity to rectify deficiencies in natural hazard planning for karst in Virginia. To comply with Section 322, local governments will and should devote a majority of their hazard planning efforts to potentially catastrophic natural hazards like flooding, winter storms, high wind events, and wildfires. In western Virginia, development on karst terrain exposes communities to several natural hazards including sinkhole subsidence, sinkhole flooding, and groundwater contamination. Full compliance with the letter and spirit of Section 322 requires local governments to consider and address all natural hazards present within their jurisdictions. This requirement provides local governments with an opportunity to rectify the current paucity of land use planning and management for karst terrain natural hazards in western Virginia.

Responses to the Karst Protection Survey conducted, in part, by the author, indicate that a majority of communities in western Virginia reference karst, sinkholes, and/or groundwater in their comprehensive plans. However, only Clarke County and Loudoun County have gone on to develop a comprehensive set of land use planning tools to guide development on karst terrain.

While devoting resources to natural hazard planning local governments in western Virginia should also address the potential effects of karst related natural hazards, which affect up to 60 percent of the land area of some communities in western Virginia. Counties, cities, and towns in western Virginia need not "re-invent the wheel" when developing karst hazard mitigation strategies. The initiatives of local governments in Virginia and throughout the United States provide a wide assortment of potential mitigation strategies for inclusion in a karst hazard mitigation plan. By modifying many familiar land use planning tools local governments in western Virginia can successfully reduce future hazard risks associated with development in karst terrains.

The following discussion proposes a four-step planning process, summarized in Table 4.1, for local governments to follow in the development of local karst hazard mitigation plans. The process starts with community education and partnership building to develop community support and commitment for the subsequent steps in the planning process. The karst terrain risk assessment and vulnerability analysis clarifies the hazards that local karst terrain poses to a community. In the final two steps, local governments develop both regulatory and non-regulatory mitigation strategies to minimize community exposure to local karst terrain natural hazards. By using a karst terrain buffer and overlay hierarchy local governments can target regulatory and non-regulatory mitigation strategies to those karst areas that pose the highest natural hazard risks.

Table 4.1 - Karst Terrain Hazard Mitigation Plan Development Process

I. Community Education and Partnership Building

II. Karst Terrain Hazard Assessment
- **A.** Develop a karst feature classification system
- **B.** Develop a karst buffer and overlay hierarchy system
- **C.** Develop geographic information system capabilities for karst terrain hazard planning

III. Develop Regulatory Karst Terrain Hazard Mitigation Strategies
- **A.** Update the subdivision ordinance to reflect community goals and objectives for development on karst terrain
- **B.** Develop a karst terrain zoning overlay district requiring:
  - i. effective karst feature buffers
  - ii. geotechnical studies for development on karst terrain
  - iii. karst terrain related performance standards
- **C.** Enforce Virginia stormwater management regulations
- **D.** Enforce Virginia erosion and sediment control regulations
- **E.** Enhance Virginia septic system regulations to better address the unique geo-hydrology of karst terrain
- **F.** Develop spring and wellhead protection policies that reflect the unique geo-hydrology of karst terrain

IV. Develop Non-Regulatory Karst Terrain Hazard Mitigation Strategies
- **A.** Use capital improvements programming to steer development away from high-risk karst terrain
- **B.** Encourage voluntary land use restrictions in karst terrains through the use of:
  - i. Conservation easements
  - ii. Purchase of development rights
  - iii. Agricultural and forestal districts
  - iv. Land use assessment and taxation programs

Community Education and Partnership Building

"Enlisting community help and support in formulating a hazard mitigation plan and seeing mitigation measures adopted is the essential first step in [natural hazard mitigation] planning" (Godschalk, *et al*, 1998: 96). Community education is one of Virginia's top five natural hazard mitigation strategies (Virginia Department of Emergency Management, 2001). It should also be a top priority for all local hazard mitigation plans. Because karst terrain hazards are rarely obvious to the casual observer and are usually chronic, rather than acute, in their effects, they rarely result in the type of newsworthy natural hazard events that make it on to the evening news. For these reasons, a community's inherent awareness and understanding of karst terrain hazards is likely to be much less than their knowledge about flooding, winter storms, and wildfires. Consequently, the development of even minimal community understanding, support, and demand for karst terrain natural hazard planning depends on effective community education beginning as early as possible and continuing through the entire hazard planning process. The education process should address (1) natural hazard mitigation planning, (2) karst terrain hazards, and (3) potential land use planning techniques available to address these issues.

The education process is both the product of and results in local government collaboration with numerous stakeholders in the community. The development of a wide range of partnerships increases the efficacy, cost-effectiveness, and local community support for natural hazard mitigation planning and the adoption of associated mitigation strategies. Because no centralized karst terrain "data warehouse" or funding resource exists, local governments must include a wide diversity of partners in the karst terrain hazard planning process. Table 4.2 provides an incomplete list of potential partners available to assist local Virginia governments in karst terrain natural hazard mitigation planning. The table includes federal and state government agencies, regional/quasi-government agencies, third sector[5] partners, and private/for-profit partners. All of the potential partners on the list hold expertise in karst terrain hazards, natural hazard and land use planning, and/or drinking water protection.

Table 4.2 – Potential Partners for Karst Terrain Hazard Mitigation Planning

Sector	Name	Area of Expertise*
Federal Government	Natural Resources Conservation Service	KT
	U.S. Geological Survey	KT
	Federal Emergency Management Agency	NHMP
	U.S. Environmental Protection Agency	KT/DWP/NHMP
Virginia State Government	Department of Emergency Management (VDEM)	NHMP
	Department of Environmental Quality	KT/DWP
	Department of Conservation and Recreation (DCR)	KT
	Virginia Karst Program (part of DCR)	KT
	Natural Heritage Program (part of DCR)	KT
	Department of Health	DWR
	Department of Mines, Minerals and Energy	KT
Regional and Quasi-Government	Planning District Commissions	NHMP
	Soil and Water Conservation Districts	KT
	Resource Conservation and Development Agencies	KT
	Public Service Authorities	DWR
Third Sector	National Speleological Survey	KT
	Virginia Speleological Survey	KT
	Cave Conservancy of the Virginias	KT
	Cave Grottos	KT
	State and Regional Universities	KT & NHMP
	Private citizens	KT
Private Sector	Consultants	KT

* Areas of Expertise
DWR: Drinking Water Regulations; NHMP: Natural Hazard Mitigation Planning; KT: Karst Terrain

5 "The third sector – also known as the nonprofit, nongovernmental, independent, or voluntary sector – encompasses everything from large-scale nonprofit institutions with professional staff to informal grassroots entities with no budget, no real legal status, and only good will and volunteerism as their principle resources (Paterson, 1998: 204)."

Karst Terrain Hazard Risk Assessment and Vulnerability Analysis

One of the first steps in the development of any natural hazard mitigation plan is the identification and mapping of natural hazards. Section 322 requires the identification and location of natural hazards along with community facilities, resources, and populations vulnerable to the natural hazards (Federal Emergency Management Agency, 2002).

The Risk Assessment and Vulnerability Analysis process provides (1) a prioritized hazard list, (2) hazard profiles for each hazard on the list, (3) a critical facilities inventory, (4) vulnerability descriptions, maps, and/or tables, (5) potential loss statements for each hazard, and (6) a description of the growth and development trends that will increase (or decrease) the community's vulnerability. The natural hazard mitigation planning process then uses this information to develop hazard mitigation goals, objectives, and strategies.

By adopting a karst feature classification scheme for local karst features including sinkholes, caves, sinking creeks, etc. communities more accurately identify local karst terrain hazard risks. The use of a complex classification scheme like *A Sinkhole Classification Scheme for Virginia's Karstlands* (Orndorff, 2001) allows local governments to maximize their understanding of the hazard risk posed by individual karst features.

A karst feature buffer and overlay hierarchy system clarifies the levels of karst hazard risks resulting from current and proposed land uses adjacent to or within the drainage basins of karst features. The author proposes a model karst feature buffer and overlay hierarchy system at the end of this chapter.

By combining karst GIS spatial and attribute data from state, regional, and local sources, including karst feature buffers and overlay areas, local governments create a valuable natural hazard planning tool. Including GIS data for abandoned wells, active wells and springs, septic systems, source water protection boundaries, hazardous waste storage sites, ground water dye-tracings, streams, etc. enhances this planning tool. Information gathered in geotechnical studies adds detailed site-specific karst hazard information.

Develop Regulatory Karst Terrain Hazard Mitigation Strategies

Once local governments identify karst hazard areas, they control, discourage, and prohibit land development in hazardous karst areas through the enforcement of a variety of regulatory karst terrain hazard mitigation strategies. Ensuring that the subdivision ordinance reflects local land use planning goals and objectives for development on karst terrain reinforces other community karst related ordinances, regulations, and policies. Zoning overlay districts with language requiring karst feature buffers, site plans based on geotechnical studies, and the achievement of karst related performance standards have proven effective tools in managing land use in karst areas. Local governments in Virginia can model new karst zoning overlay districts on similar overlay districts already in use in Virginia and throughout the United States.

The adoption and effective enforcement of the Virginia Stormwater Management Regulations and the Virginia Erosion and Sediment Control Regulations help maintain predevelopment subsurface recharge and discharge in karst areas. Enhancing Virginia's *Sewage Handling and Disposal Regulations* (2000) to address the unique geo-hydrology found in karst terrain protects local groundwater and surface water quality. The adoption of spring and wellhead protection policies, appropriate to karst terrain, further ensures the quality of local groundwater drinking sources.

Develop Non-Regulatory Karst Terrain Hazard Mitigation Strategies

Non-regulatory hazard mitigation strategies limit community exposure to karst hazards by limiting development in high-risk karst areas. By encouraging voluntary land use restrictions for high-risk karst terrain local governments also limit potentially large financial expenditures that may otherwise be necessary to prohibit undesirable development in karst areas.

By including karst terrain hazard considerations in the capital improvement programming process local governments steer high-density land development away from those areas that pose the greatest hazard risk. This strategy also protects a portion of a community's green infrastructure, ensuring the proper functioning of natural karst terrain processes that benefit the community.

Encouraging private landowners to permanently protect individual karst features, and associated buffers and drainage basins, also helps steer high-density development away from high-risk karst areas and protects local green infrastructure. Conservation easements and the purchase of development rights permanently protect significant karst areas as open space. Inclusion of karst features, buffers, and drainage basins in agricultural and forestal districts and in land-use valuation systems provide landowners with tax incentives to temporarily prohibit development in high-risk karst areas until resources are located for their permanent protection.

Model Karst Terrain Overlay and Buffering Hierarchy

Land use planning and management tools often delineate a set of regions or zones around important natural resources to buffer or mitigate the affects of surrounding land uses on vulnerable natural resources. Land use restrictions within these zones increase as one approaches the natural resource being protected. The Virginia Source Water Assessment Program uses a fixed radius delineation method to define two zones of concern for public drinking water source protection (Virginia Department of Health, 1999). The Virginia Department of Forestry (2002) recommends the delineation of Streamside Management Zones (SMZ), unharvested, vegetated areas adjacent to water bodies left to protect water quality also known as riparian buffers. The widths of these buffer zones reflect the relative vulnerability of a water body to near-by silviculture activities.

The Virginia Chesapeake Bay Preservation Act (Bay Act) (9 VAC 10-20-10 et seq.) provides a two-tiered natural resource protection model adaptable to karst areas. The Bay Act requires local governments in the Tidewater area of Virginia to designate Chesapeake Bay Preservation Areas (CBPA) in order to protect vulnerable water bodies like Bay tributary streams, estuaries, and non-tidal wetlands, from water pollution that will degrade the health of the Chesapeake Bay. Local governments subdivide the CBPA into two regions reflecting the potential risk for water pollution posed by land uses in each area. Resource Protection Areas (RPA) consist of "lands adjacent to water bodies…that have an intrinsic water quality value due to the ecological and biological processes they perform or are sensitive to impacts which may result in significant degradation to the quality of state waters" (Chesapeake Bay Local Assistance Board, 2001). RPAs require the most stringent land use restrictions in the CBPA. Resource Management Areas (RMA), with less restrictive land use regulations, include areas contiguous with the entire inland boundary of the RPAs. RMAs buffer RPAs by prohibiting land uses that could cause significant water quality degradation or diminish the functional value of the RPAs (Chesapeake Bay Local Assistance Board, 2001).

The author proposes that local governments in western Virginia use the CBPA model to develop a four-tiered karst terrain buffer and overlay hierarchy that applies increasingly stringent land use restrictions the closer one is to a vulnerable karst feature. The broadest category in the buffer and overlay hierarchy is the Karst Terrain Area (KTA) (author's term). Because carbonate bedrock is the type of bedrock most likely to develop the numerous surface and sub-surface features that characterize karst terrain, the extent of carbonate bedrock like limestone and dolomite define the boundaries of the KTA. Many existing karst related overlay zoning districts reflect this reasoning (West Whiteland Township, PA, 1986; North Jersey RC&D, undated). In some western Virginia counties, the proposed KTA covers hundreds of square miles (Virginia Speleological Survey, 2003). To apply the strict land use restrictions necessary to protect individual karst features to this entire area proves both politically and economically infeasible.

The KTA indicates to community members areas where potential karst terrain hazards are likely to occur. The identification of Tidewater communities as primary areas of concern – thus justifying the required mandatory compliance with the Chesapeake Bay Preservation Act in these communities - in the CBPA model parallels the identification of broad areas underlain by carbonate bedrock as KTA. The KTA indicates where (1) proposed development requires a geotechnical study, (2) additional zoning overlay karst considerations apply, (3) enhanced septic system, wellhead and spring protection ordinances apply, (4) to target land preservation funding, and (5) to steer capital investment funding away from.

The KTA contains numerous individual karst features like sinkholes, sinking creeks, and caves. Strict land use restrictions prohibit nearly all land uses within the boundaries of individual karst features as these areas pose the greatest natural hazard risks. This prohibition effectively dedicates actual karst features as permanent open space.

A karst feature buffer surrounds each karst feature. Like riparian buffers, karst feature buffers restrict land uses to maintain vegetation and forest cover within the buffer area. The vegetated buffer reduces non-point source pollution (Barfield, *et al,* 1998) and provides habitat for animals (Buchsbaum, 1994). The karst feature buffer parallels the Bay Act's Resource Protection Areas in that it designates areas that perform important water quality protection processes or in which inappropriate land uses may result in an increased karst terrain hazard risk. Many communities, like Loudoun County, Virginia, require fixed karst feature buffers extending from the edge of a karst feature. However, a karst feature classification scheme may help local governments designate a variety of buffer widths depending on the vulnerability of the individual karst feature under consideration.

The Karst Feature Drainage Basin Overlay (KFDBO) (author's term) parallels the Bay Act's Resource Management Areas. The KFDBO restricts land uses that threaten to intensify karst terrain hazards within the sensitive karst terrain overlay (described below) or diminishes the functional value of the karst feature buffer. The author draws the KFDBO concept directly from recommendations by Kastning and Kastning (1997) to base karst feature buffers on karst feature drainage basins in order to better identify and minimize potential karst hazards resulting from development in karst terrain. The KFDBO is based on any of several criteria including (1) the boundary of the drainage basin that contributes recharge to a sinkhole or a clustered sinkhole infiltration system, (2) the area within the contributing basin that is under development, (3) the natural settings, including topography, geologic parameters such as bedrock and structure, and vegetative cover, (4) inherent storm-water hydrological responses, and (5) proximity of land use activities within the basin that may impact discharge and recharge at the sinkholes (Kastning & Kastning, 1997). In addition to providing an intermediate land use restriction category the act of delineating the true boundaries of karst feature drainage basins raises awareness about the potential hazards related to land use development around such features (Kastning & Kastning, 1997).

Finally, a sensitive karst terrain overlay (SKTO) (author's term) parallels the CBPA and identifies areas of relatively high karst feature concentrations, which pose the greatest natural hazard risks within the KTA. The SKTO includes multiple karst features and their associated buffers and KFDBO. The SKTO reflects the extent of "karst land" identified on geological quadrangles developed by the Virginia Department of Mines, Minerals, and Energy (for an example of one of these maps, refer to Bartholomew & Lowry, 1979). Land use restrictions more limiting than those of the KTA, but less stringent than those required in the KFDBO, apply to all development within the SKTO.

The application of a four-tiered karst feature overlay and buffer delineation program clearly identifies areas at greatest risk to karst terrain natural hazards. It allows local governments to apply the strictest land use regulations to those karst areas most vulnerable to land use development. At the same time, the clear delineation of differing sensitivities within karst areas provides valuable public education necessary in any natural hazard planning process.

<u>Conclusion</u>

Development on karst terrain poses many natural hazards that local governments can minimize through pro-active land use planning and management. By following the planning process delineated in this chapter local governments build community understanding and support for the various mitigation strategies applicable to local karst terrain hazard areas. Effective natural hazard assessment allows for the relatively precise targeting of regulatory and non-regulatory mitigation strategies to minimize the impact of land use restrictions on the general community, while maximizing the hazard mitigation efficacy of the chosen strategies. By taking advantage of the numerous hazard assessment and regulatory and non-regulatory mitigation strategies pioneered by local governments both within and outside of Virginia, local governments can develop effective karst terrain hazard mitigation plans.

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EDUCATION

Masters of Urban and Regional Planning – Environmental Planning and Policy Concentration and Watershed Management Certificate,
Major Paper Topic: Natural Hazard Mitigation Planning for Virginia Karst Regions
Expected May 2003, Virginia Tech, Blacksburg, VA
Member of the Honor Society of Phi Kappa Phi

Post Baccalaureate studies in Environmental Resource Management,
August 2000 – May 2001, Virginia Tech, Blacksburg, VA

BA in Cultural Anthropology, *cum laude,* with minors in business and history,
May 1998, James Madison University, Harrisonburg, VA

WORK EXPERIENCE

***Graduate Research Assistant*, August 2002-May 2003**
Dept. of Urban Affairs and Planning, Virginia Tech, Blacksburg, VA
Authors Karst Protection Survey of local governments to determine the impacts of karst on local land-use regulations in Virginia and West Virginia; analyzes and summarizes survey data; develops extensive annotated bibliography of karst land-use regulation literature; co-authors final report for the Cave Conservancy of the Virginias (grant sponsor).

***Continuous Forest Inventory Technician*, Summer 2001**
Maryland Department of Natural Resources, Green Ridge State Forest, MD
Worked in two-person team to measure forest health, species composition, recent environmental / human impacts, growth rate, etc. for 120 sample plots throughout the 54,000 acre state forest; developed and executed daily, weekly, and monthly team project goals; and maintained computer and hard copy records of field data.

***Research Associate*, June 1999-December 2000**
Building Codes Assistance Project, Washington, D.C.
Researched and authored newsletter regularly distributed to over 1000 stakeholders; wrote white papers and information articles; and achieved position requirements and responsibilities while telecommuting from home in Blacksburg, VA from August to December 2000.

***Visitor Use Assistant*, Summers 1997 and 1998**
Klondike Gold Rush National Historical Park, Skagway, AK
Staffed visitor information desk; acted as liaison between backcountry staff, park visitors and Parks Canada staff; assisted Parks Canada in the processing and distribution of limited backcountry use permits to the public; researched, authored and presented to park visitors a regular series of 1 - 1 ½ hour cultural and natural history presentations; acted as emergency Backcountry Trail Ranger; and earned Special Service Award.