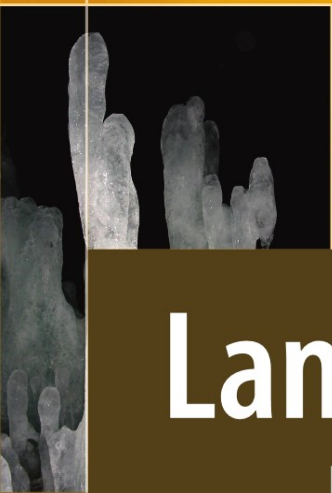
Spencer Fleury



Land Use Policy and Practice on Karst Terrains

Living on Limestone

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Preface

At its core, this book is about understanding what happens when karst systems and human systems overlap, and what we can do to control the outcome of those cross-system interactions. Some of the social science disciplines—geography and economics in particular—have theoretical underpinnings that predict karst-related land use regulations are likely to have particular impacts on certain aspects of human systems, like housing densities or overall economic health. But does any of that actually happen? Can we identify and quantify any examples? And if so, are these impacts significant enough that land use planners and policymakers should consider them during the regulation writing and implementation process?

In writing this book, I've tried to put together a solid overview of how land use regulations are used to control and regulate human activity on karst lands in the United States, what some of their actual impacts seem to be, and to draw upon that information to propose a generally applicable framework for the development of karst regulation. In the chapters that follow, I will describe how karst systems work and the ways in which human activity can interfere with them; I will explore the various regulatory techniques used to manage land use in karst areas throughout the United States; I will examine the thoughts and experiences of the planners who work with these regulations every day; I will describe some real-world examples of how karst aware land use regulations have impacted the cities and towns that use them; and finally, I will propose a basic framework by which we can better understand karst land use regulations.

Contributing to the development of this framework is the main goal of this book. It will be built upon the data collected and the conclusions discussed in the following chapters and is intended to provide a description not just of the inputs and processes that go into developing karst regulations and ordinances, but also a broad examination of the ways in which various inputs interact and the effect those interactions have on the form that these regulations ultimately take. Since this is the first attempt to develop this sort of framework, it is best understood as a starting point in the process of creating a more detailed and refined model of the karst policy creation process.

It's true that a policy-based approach won't necessarily keep thoughtless people from pouring out their used motor oil in or around sinkholes. Certainly, individual behavior is more likely to be affected by education and public relations than by books on land use policy. My hope in writing this book is to contribute to a big-picture understanding of how myriad factors in the karst land use regulation process impact the human systems that choose to implement them. Because the potential audience for this book ranges from the academic and scientific community to working land use planners, some of the more technical aspects of karst systems are either simplified or not discussed herein. This decision was made in the interests of simply communicating the concepts underlying my research to a wider professional audience, and because there are several authoritative, technically-oriented sources for information on karst and karst systems already available. Should you wish to read a more technical explanation of how karst works, I suggest you begin with either White's *Geomorphology of Karst Terrains* (1988), or Ford and Williams' *Karst Geomorphology* and Hydrology (2007).

Tampa, Florida S. Fleury

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Chapter 1
Karst Processes, Landforms and Issues

Abstract Karst systems are often extremely sensitive to the nature of human activities taking place on the surface. Pollutants and contaminants can wash into karst landforms and downward through cracks and fissures in the hard carbonate bedrock, rapidly entering the aquifer below. Because so much of the world's population (some sources estimate as much as 25%) draws drinking water from karstic aquifers, there is a significant incentive to understand and develop land use regulations that work to prevent the inadvertent contamination of groundwater supplies in karst landscapes. This chapter acts as an introduction to the topic, describing the processes by which karst features form, identifying several of the most common karst landform types, and providing examples of instances in which careless or unmanaged human–karst interaction had negative results.

Keywords Groundwater · Aquifer contamination · Land use policy · Karst processes · Human–karst interaction

Karst Aquifers: Fragile, Threatened and Vital

Hundreds of years ago in western Ireland, the local population turned to deforestation as a fuel source to drive its growing metalworking industry. Their aggressive approach to cutting down trees had the unforeseen consequence of clogging—and eventually drying up—the local aquifer. As a result, this once-productive landscape quickly turned into a scarred and barren wasteland (Back 1983).

Something similar happened several centuries later and half a world away. During the 20th century, southwestern China underwent an intensive process of industrialization. For decades, hundreds of factories there have discharged severe pollution into the air, toxins that eventually fall out of the air and collect on the ground and in surface waters. The pollution from these factories was bad enough to strip most vegetation from the landscape; here, too, rainwater was unable to seep into the aquifer and recharge it on a regular basis. It soon suffered the same fate as the western Irish aquifer (Back 1983).

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In the Yucatan Peninsula, Spanish explorers brought with them the technology to extract groundwater from very deep wells. This made it easier to settle and tame the lands further from the coast, which in turn attracted more and more new settlers. Eventually, water-intensive agricultural practices (like growing sugarcane and hemp) grew to become a key cog in the local economy. All this environmental stress over all these years was simply too much for the landscape to bear, and as a result, by the early 1900s the aquifer had become a "virtual sewer" (Back 1983).

In Allentown, Pennsylvania, in 1979, the bottom of an industrial retention pond crumbled and gave way, dumping the pond's contents directly into the local aquifer (Memon and Azmeh 2001). The same thing happened at a golf course in Pinellas County, Florida, in 1988 (USGS 1999). Both of these retention ponds were located directly above sinkholes; fortunately, in both cases the actual damage to the aquifer was manageable.

What do all these incidents have in common? Each resulted from inappropriate land use practices in karst terrains, and each could probably have been mitigated or avoided completely if the people living there had used a bit more foresight and care when deciding how to use those lands. Of course, in medieval Ireland and 18th-century Mexico, nobody knew anything about karst landscapes or what could happen when those landscapes are subjected to the stresses of human-driven change. Nor is it likely that local peoples clearly understood the relationship between land use practices and local environmental health to begin with.

Still, these incidents provide a stark lesson in the dangers of inappropriate land use practices in karst terrains and an example of just how serious the environmental consequences can be. Unfortunately, these same problems seem to keep coming up again and again. For example, the karst resources in the Apuseni Natural Park, located in northwestern Romania, are threatened by aggressive deforestation, among other things. The park has recently implemented a management plan that spells out methods for protecting these resources, but the Romanian park service is subordinate to the national forestry service, which wants to maximize the return on the forest stands in the park. The park's caves (caves are perhaps the best known and most visually arresting type of karst landform) and aquifer are already threatened by the growing interest in nature tourism there; cutting down too many trees could ruin them completely.

What Is Karst?

The term *karst* is used to describe a specific type of landscape. Karst landscapes form under a specific combination of geological conditions, precipitation, and temperature. When rainwater seeps downward through the topsoil, it picks up carbon dioxide from the decaying organic matter found there and becomes a weak carbonic acid. In places with hard carbonate bedrocks (limestone is the most common, but other possibilities include dolomite and gypsum), the hardness of the bedrock prevents this acidic solution from seeping into it and, over the course of months or years, making its way into the aquifer, all the while undergoing a slow filtration process that naturally removes many contaminants picked up on the surface. Instead, the carbonic acid seeks out cracks and crevices in the bedrock, where a chemical reaction occurs and the bedrock is slowly eaten away. Eventually, this process widens these cracks and crevices to the point where they become caves, sinkholes, or springs. Because these landforms develop by widening gaps in the bedrock, they can eventually grow large enough to act as direct pathways from the surface to the aquifer. Any surface water washed into these landforms can make its way into the groundwater in a matter of minutes, carrying with it a full load of toxins and contaminants collected from streets, parking lots, industrial sites, or landfills (White 1988; Ford and Williams 2007).

If one were to randomly pick a hundred people off the street and ask them what karst is, the vast majority—maybe even all of them—would probably not be able to answer. But karst landscapes are actually very common. Numbers vary when it comes to estimating how much of the world is actually karstic: Williams (1993) places the figure at 25% of the earth's surface; White et al. (1995) put the worldwide figure at 20% of the earth's dry land surface, including fully 40% of the United States east of the city of Tulsa, Oklahoma. Regardless of whose estimate is more accurate, it is clear that hundreds of millions of people worldwide live and rely on karst landscapes.

Still, karst and karst-related issues are frequently overlooked by the general public, including those who live in heavily karstified areas and are most likely to suffer consequences from inappropriate (or even irresponsible) land use decisions. Many of these karst landscapes are found in urbanized areas, where they face a much higher likelihood of impacts from human activities. For one thing, karst aquifers are often used as sources of drinking water, not only for people who live on the karst lands themselves, but also for people who live nearby and lack convenient access to other water sources—some estimates say that 25% of all human beings get their water from karst aquifers (Ford and Williams 2007). Water from karst aquifers is also frequently used for industrial and agricultural purposes, making it an important input into many local or regional economies. But because of the specific physical characteristics of karst, these aquifers are particularly susceptible to contamination or other human-driven damage. Naturally, this can have severe effects on drinking water supplies; sometimes, it can even leave the water useless for industrial and agricultural purposes.

There are also other important karst-related issues that are not necessarily tied directly to groundwater quality. Pumping too much groundwater from a karst aquifer too quickly can by itself lead to new sinkhole formation and land subsidence, which has the potential to cause significant property damage and occasionally even threaten human life. And karst landforms—especially caves—offer a wealth of information for a wide range of scientific disciplines (geology, geomorphology, biology, climatology, etc.). When caves suffer damage, the ability of scientists to conduct new research in these and other fields is hindered; the fact that it often comes as the result of careless land use practices makes it all the more tragic.

In the end, the issue is a simple one: karst landscapes are simultaneously valuable and fragile, and humans have a long history of damaging or destroying karst systems by pushing the landscape's ability to support human activity to the breaking point and beyond (Back 1983). It helps to think of karst landscapes as systems, each with a specific set of conditions required to maintain equilibrium. Similarly, human societies can be seen the same way, as systems with their own equilibrium conditions. Because these systems often interact with each other, changing one variable—surface water runoff paths, for example—in one system can easily bring dramatic change to the other system. Unless we are prepared to intervene through the regulatory process in this interaction of systems, one or both of them may soon wind up unable to maintain equilibrium, resulting in environmental degradation.

In the United States, it's not hard to find examples of land use or other human activities that pose a potential danger to karst systems, especially in densely populated, urbanized karst landscapes. Many jurisdictions impose some limitations on how land may be used in the vicinity of karst landforms. Sometimes these restrictions are serious enough to prevent, or at least hinder, inappropriate development. But more often, they are minor, even negligible, and seem less likely to have any noticeable or meaningful impact on land use patterns. That should not be surprising, since unique local conditions often play a major role in shaping the details of land use regulation. Different places face differences in the availability of data or specialized technical knowledge, differences in local political climates and priorities, and differences in the extent of the karst systems in question. Places without a strong tradition of land use regulation might also be hampered by the absence of a generally accepted approach to developing karst-related land use regulation or the lack of a comprehensive understanding of how karst land use regulation works. As a result, local governments and other regulating entities in karst terrains are usually left to their own devices to create the appropriate tools for regulating land use and development. This is not a problem in cities and towns that have the expertise to do it, but not all municipalities do, making it more difficult to develop regulations that are both appropriate and effective. There's also the issue of duplicating effort and wasting resources, when perfectly serviceable regulations from other cities, towns and counties are available to borrow and adapt as necessary.

As with any form of land use regulation, efforts to introduce karst-related restrictions on land use and development are likely to run into serious resistance. One of the most likely sources of this resistance is the community of land speculators and developers who believe that any impediments to new construction cost them money. In some cases, these people have considerable influence over the process of writing and implementing new regulations, but that is far from a universal truth. Regardless of whether or not the construction industry has the clout to block what they consider to be onerous new regulation, it is a good idea for any new regulatory scheme to be (a) appropriate for the karst system and (b) as unobtrusive as possible for the people who live there. Of course, the latter requirement is more important in urbanized karst areas than in protected areas like national parks, which generally have low population densities.

Karst Landscapes: An Introduction

Karst landscapes form in areas with carbonate bedrock. Over time, the bedrock is subjected to slow dissolution processes caused by a particular combination of temperature, chemistry and soil acidity. This process typically results in the formation of visible surface and subsurface features, including sinkholes, caves, and springs. In karst terrains, water is the main agent of landscape change; the role of mechanical erosion processes is much less significant (White 1988; Palmer 2007; Ford and Williams 2007).

It is important to remember that this water must be slightly acidic in order for any karst processes to take place. Surface water can turn into a weak carbonic acid solution as it seeps through the topsoil and picks up carbon dioxide left by decaying biological material. When this acidic water comes into contact with the carbonate bedrock, it seeks out the cracks and fissures in the rock, which are then gradually widened as the calcite reacts with the carbonic acid. This reaction can take as long as several minutes to begin, depending on specific site conditions like temperature and acidity; when it does occur, most of the water's dissolution potential is spent over the space of just a few meters (Palmer 2007; Dreybrodt 2004; Dreybrodt 1988). Once dissolution of the bedrock begins, a network of grooves and clefts forms on the bedrock's surface and enables the surface water to descend more quickly into the subsurface, where it expends the remainder of its dissolution potential in the bedrock's joints and fractures. Dissolution conduits then form along these fractures, which grow larger as more of this slightly acidic water continues to drain into them (Fig. 1.1). This is a long-term process, generally requiring thousands of years to produce an opening in the bedrock extending for 100 m or more. These gaps in the bedrock can then serve as a collector for insoluble surface material washing through the drain, leading to the formation of a sinkhole (White et al. 1995; Ford and Williams 2007; White 1988).

All karst landscapes do not look alike. At first glance, the sinkhole plains of the central United States or the Burren Karst of western Ireland would appear to have little in common with the spectacular cone-and-tower karst found in places like southwestern China and the Caribbean; yet all of these landscapes were carved via the same processes. Certainly, the actual physical form taken by karst features in any location is highly dependent on specific local conditions. While some karst landforms (for example, canyons, gorges and cliffs) can be quite spectacular and imposing, the landforms at the center of this book generally have a lower profile—both physically and in the minds of most people—than landforms like mountains, flood plains and rivers. Most karst landscapes lack the viewshed provided by these landforms—a sinkhole plain is interesting enough in its own right, but it can't compete with the visual impact of an Alpine vista, for example. This hard truth may actually be a factor in the regulatory process: i.e., a lack of widespread public awareness of or interest in karst landforms may translate into a lack of political will to regulate nearby development and land use.

Issues of land use regulation in karst terrain are nothing more than issues of human–karst interaction. In order to fully understand these, it helps to have a basic

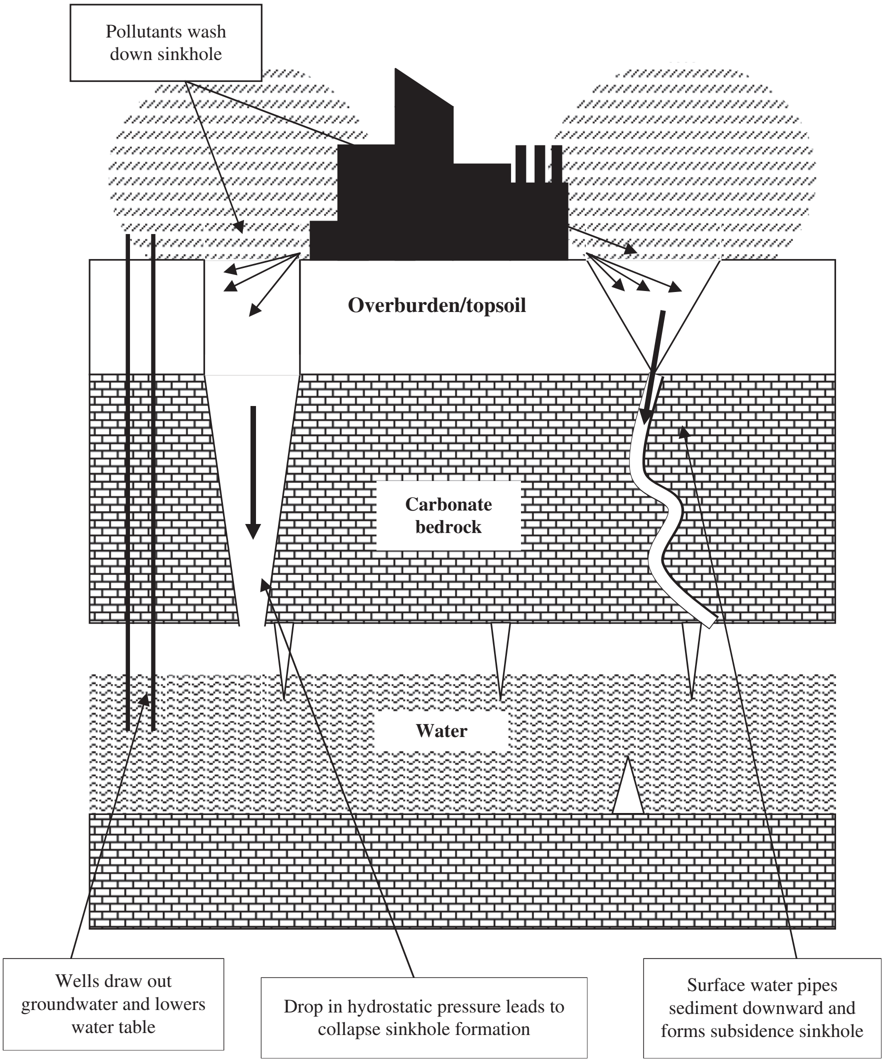

Fig. 1.1 A karst system (not to scale)

understanding of the most common karst landforms: what they are, where they form, and why they form where they do. An understanding of the land itself is a critical part of developing sensible rules for controlling the use of that land.

Sinkholes (Dolines)

Sinkholes (usually called *dolines* outside North America) are an extremely common type of karst landform, created by the subsidence of soils and rock at or near the land surface into empty spaces below. Sinkholes are often located in areas where soluble rock is near the surface, either completely exposed or beneath a layer of topsoil. In order for a sinkhole to form in the first place, there are three requirements: a drainage path for the surface water runoff to follow; a zone of bedrock modified by solution located at or near the surface; and a covering of soil or some other material making up the land surface (this last is not an absolute requirement; when that cover is absent, certain types of sinkholes can still form). Sinkhole development can then be triggered by "any mechanism that increases the head differential between the artesian water in the limestone and the perched water in the surface sands (Beck 1986)," because the downward flow and downwashing of sediment are both increased as well. The resulting depressions tend to have the shapes of bowls or funnels. There is no "standard" sinkhole size, with diameters ranging from 1 to 1000 m. Sinkhole depths of several hundred meters have been reported; however, depths of less than a meter are far more common (Ford and Williams 2007; Palmer 2007; White 1988).

There is no universal method of sinkhole formation, and the different formation processes produce sinkholes with very different surface characteristics. Some form slowly in spots where the bedrock is actually exposed at the surface (these sinkholes may eventually become lakes if their drains are plugged). Others form much more rapidly—in as little as a few hours—and come about through sudden collapse (some of the most spectacular sinkholes in the world formed this way: *Xiaozhai tinakeng*, in southwestern China, is a collapse sinkhole that is over 500 m deep and 600 m across, and other impressive examples of large-scale collapse sinkholes can be found in Papua New Guinea and Croatia); the surface collapses when enough of the clayey topsoil has been washed away. Within these two broad groups, geologists, geomorphologists and other earth scientists make distinctions between sinkhole types based on factors like the depth and the composition of surface material. It is not necessary for us to understand the distinctions at that level (Waltham and Fookes 2003).

With some exceptions, sinkholes are generally not large or spectacular landforms. However, they are important to understand in the context of karst systems because they act as recharge routes for the aquifer below. The fact that surface water receives no natural filtering when entering a karst aquifer via a sinkhole means that contaminants on the surface are easily carried into the groundwater (White 1988; USGS 1999). This issue is explored in greater detail later; for now, suffice it to say that it offers a compelling argument for more stringent management of land uses in the vicinity of sinkholes.

Caves and Caverns

It might come as a surprise to learn that the exact definition of the word "cave" is actually a topic of some debate in some disciplines of the earth sciences. However, the generally accepted definition is that a cave is a natural opening in the earth that is large enough to be entered by a human (White 1988; Gillieson 1996; Palmer 2007). Not all caves are formed via the exact karst processes described earlier: some underground caves—like, for example, Carlsbad Caverns in Carlsbad, New

Mexico—formed instead by a solution process involving sulphuric acid. Regardless of how a cave forms, there is no guarantee that any surface opening will be created—in fact, it is statistically and logically likely that there is a large class of caves that have no entrances at all (of course, under the generally accepted definition of caves, these would not actually be caves because of the inability of humans to enter them). When they do appear, cave entrances do not have to be related to the solution processes that formed the cave in the first place. Sinkhole collapse, connection to well-developed vertical shafts in the bedrock, human excavation, and the random generation of upward-sloping cave passages are common ways in which a cave entrance can form; however, thick soil covers can prevent entrances of these types from forming (White 1988; Palmer 2007).

The size and length of caves vary widely. However, the fact that a cavern narrows to the point where humans can no longer explore it does not mean that the karst drainage system ends there as well. Water draining through caves will continue through these passage terminations, sometimes to a spring outlet (Ritter et al. 1995).

Cave protection is important because of the twin scientific roles played by caves: they provide records of earth's paleoclimate, and they are ecosystems unto themselves. A cave's speleothems (also known as stalactites and stalagmites) often contain enough uranium to calculate their ages, and the oxygen isotopes they contain mean they can also offer tantalizing information about the local temperature over the geologic timescales it took for them to form. This climate information is highly localized and can be dated from speleothems with a good deal of precision and accuracy (Palmer 2007). Ecosystems not found elsewhere are able to develop in caves because of their extremely stable, long-term environmental and climatic conditions; when cave degradation occurs as the result of contact with point source or dispersed pollution sources, these fragile ecosystems are often damaged or destroyed. Even changes to the environment or landscape outside a cave can have severe consequences within the cave. For example, paving the land above a cave will almost always reduce the total amount of water passing through the karst drainage system or redirect it through new drainage routes, and the installation of nearby toilet facilities for tourists can result in bacterial contamination of waters that sustain the cave's ecosystem. However, careful planning and modern cave management techniques can help mitigate the damage caused to caves by activities like these (Gillieson 1996).

Springs

Springs are formed at the spots where karst waters emerge from the local underground drainage system. They can be found on the surface or in caves and are often used as sources of drinking water and as recreation areas. Spring formation is a direct result of carbonate rock dissolution, creating large conduits and caves that can then channel groundwater up to the land surface. Sinkholes and springs are closely related phenomena; in fact, many of Florida's 320 springs—including major springs like Silver Springs and Homosassa Springs—were originally sinkholes that became springs as sea level rose. Springs can serve as hydrological trend indicators and are very stable in terms of water quality, temperature and flow, though even short-term variation in rainfall can be reflected by a spring's flow. Large withdrawals of groundwater nearby can have serious impact on spring flow, including stopping it completely (Bögli 1980; Field 2002; Berndt et al. 1998).

Poljes

Poljes—the largest karst hollows—are wide, closed depressions with flat floors, which are often adjacent to steep enclosing walls. They require extremely thick and geographically extensive carbonate bedrock to form at all. This is due to their size: the Likapolje in Croatia, for example, measures 700 km^2 in area. Poljes are scattered throughout the world, but the vast majority are found in the area once occupied by Yugoslavia. They have their own internal drainage systems and often have complex hydrogeological characteristics, including swallow holes and disappearing streams. They are frequently used for farmland and tend to flood at least once a season. These floods can be severe, to the point where the entire polje floor becomes a lake. Flooding can sometimes be controlled and used for purposes of irrigation or hydroelectric power (Bögli 1980; Field 2002).

Karst Valleys

Karst valleys form when a developing underground drainage system diverts water away from the rivers feeding into the valley. A karst valley has all the properties of a stream valley except the stream itself. Karst valleys are more common in areas of flat, interbedded layers of limestone, sandstone and shale (White 1988).

Swallow Holes

Also known as *ponors*, swallow holes are the point at which a sinking stream heads underground. Swallow holes are surface drainage features that direct runoff into an underground channel—in other words, they are sinkholes that form in a stream bed, often with a large vertical shaft beneath. In poljes, the original swallow holes are often dry, but still act as a conduit to the karst aquifer (Bögli 1980; Ford and Williams 2007).

Residual Hills

These can sometimes be found where thick layers of limestone are exposed on hillsides. Runoff may carve drainage pathways out of the side of one of these hills, as it is a more efficient method of transporting the water to the hill's base. These pathways can take the form of vertical shafts, solution chimneys or even open joints or fractures (White 1988).

Cockpit Karst

Cockpit karst landscapes are generally found in thick limestone, usually in tropical climes—the most notable cockpit landscapes are found in Jamaica and on the Indonesian island of Java. Cockpit landscapes can be quite wide, with diameters of a kilometer or more, and will sometimes grow large enough to develop subsidiary channel systems (Day and Chenoweth 2004).

Cone-and-Tower Karst

Cone-and-tower karst is closely related to cockpit karst. These landscapes typically evolve from residual hills and have almost completely vertical sides, as well as a distinct uniformity of size: at Gunung Sewu in Java, for example, most hills are close to 50 m high. Deep pits can often be found at the top of these hills; in some cases, high concentrations of caves can also be found. They are found primarily in tropical regions, like Cuba, Puerto Rico, South China, Vietnam, and New Guinea, usually in areas where karst processes have been underway for a considerable amount of time (White 1988; Field 2002).

The Geographical Distribution of Karst Landscapes and Landforms

Some karst landforms are far more likely to appear in certain places than in others. This is because local climatic and geographical conditions are major determinants of which types of karst landforms, if any, will develop in a given location. Evidence of this can be seen in worldwide patterns of geographic distribution of karst landforms.

Limestone regions are found throughout the world, at all latitudes and in every climate. However, presence of limestone bedrock does not necessarily mean that a karst landscape has developed or will ever develop there. Karst regions are much more likely to develop in temperate regions and tropical zones; examples include the karst regions of the eastern United States, the Yucatan Peninsula area of Mexico and Central America, western Cuba, and parts of Southeast Asia and Indonesia.

Why doesn't karst form in polar regions? Simply put, because it is just too cold there. In order for karst landscapes to develop, there must be water that contains dissolved carbon dioxide. Ambient temperature is a major influence on the ability of water to dissolve carbon dioxide from the atmosphere, with colder water having a greater potential to carry carbon dioxide in solution. On its own, this would suggest that karst landscapes would be more likely to develop in polar zones than tropical zones. However, soils in warmer areas can produce more carbon dioxide than colder soils, which more than cancels out the advantages of cold water's CO_2-carrying capacity.

Karst landforms will not develop in areas without adequate precipitation, regardless of climate. However, inactive karst formations are often found in arid areas, suggesting these dry places had wetter climates in the past. That said, it should be kept in mind that chemical solution of carbonate rocks is a complex process, so much so that it makes climate-based prediction of karst outcroppings difficult and unreliable (Ford and Williams 2007).

Global and regional distributions of karst landforms can therefore be explained by the presence of limestone and by certain temperature-related parameters. How, then, can we explain the local distribution of karst landforms? As it turns out, that question is a bit trickier to answer. Spatial distribution can be plotted by looking at depression density, sinkhole areas, relative spacing between sinkholes, and through use of other spatial techniques. However, an explanation of what actually drives the spatial distributions of karst landforms has been elusive. Some studies have shown that local distribution of sinkholes is independent of the bedrock, and a study of the karst of northern Iowa showed that depression density (measuring the number of entry points of internal runoff water into the subsurface) increases rapidly with the age of glacial drift covering, but levels off soon thereafter (White 1988). Nevertheless, there are some guidelines for determining which sites in a given karst region are more prone to sinkhole development. First, areas with steep slopes tend to produce fewer sinkholes—not surprising, since steeper slopes mean that surface water runoff is likely to roll right past a sinkhole drain. Second, areas with denser, less porous limestone bedrock are more likely to display sinkhole formation where joints in the dense limestone promote drainage at specific locations. And finally, areas with soil and vegetation cover usually promote solution processes, due to the presence of carbon dioxide in the soil (Ritter et al. 1995).

Localized cave distribution is a bit easier to examine, though it is not without its difficulties. Most large groups of caves—like those found in the Potomac River Basin or in Alabama, for example—produce smooth distribution functions when grouped by length. The distribution of caves according to length can be analyzed using certain statistical processes that eventually generate a "karst constant," which describes the cave length distribution for a given area or region. It's important to remember that there are some shortcomings in cave length distribution measurement as well: the legal definition of a cave can vary from state to state or country to country, and there is probably a large class of caves with no entrances at all that is simply not included in these analyses (White 1988).

Issues of Human–Karst Interaction

Rarely are human societies able to avoid having an impact on the landscape they occupy; this is even truer for societies in fragile environments, like karst terrains. Cities, towns and agricultural enterprises located above or near karst systems often alter the conditions necessary for equilibrium in those systems; it's very easy for human society to induce cave degradation, groundwater contamination, and land subsidence in karst landscapes. In turn, these impacts often define how and to what extent humans can interact with the karst landscapes they occupy.

Subsidence

In karst terrains, subsidence is observed in the form of new sinkholes. This is a common occurrence in karst areas experiencing rapid urbanization and has happened in many urbanizing karst terrains throughout the world. In the 1970s, Spain's Central Ebro Basin underwent the beginning of large-scale urbanization and industrial development. The presence of karst was not taken into account during either the planning or construction phases of development, and over the next several years a large number of sinkholes formed in the area. Since then, these sinkholes have caused significant damage to buildings, roads, and water supply systems, as well as the loss of arable farmland. Subsidence incidents in the Chattanooga, Tennessee area, also began to occur with more frequency during the late 1970s; this spike was coincident with increased groundwater pumping for industrial uses in the area (Soriano and Simon 2002; Wilson 1984).

The subsidence events in the Central Ebro Valley and in the Chattanooga area were almost certainly a direct result of aquifer drawdown that accompanies the urbanization process in karst regions. In urbanizing karst areas, the underlying aquifer comes under severe pressure as demand for water skyrockets. The most common strategy to meet this new demand is to pump more water from the ground, at what often turns out to be an unsustainable rate. This overextraction of groundwater can cause the formation of voids, as spaces that once held water are emptied. Once that happens, there is suddenly less pressure on the land surface from below ground, and subsidence and collapse into these voids can happen at any time (Patton and DeHan 1998).

Rapid aquifer drawdown is not the only cause of sinkhole formation in urbanizing karst areas. For one thing, the extra weight and pressure applied to the land surface by new structures and infrastructure can cause sinkholes to develop long before they might otherwise have done so. Construction activities that alter surface water drainage patterns can also induce new sinkholes by increasing the flow of surface water through existing sinkhole drains. This was the cause of the February 2002 Dishman Lane collapse, in Bowling Green, Kentucky. This concentration of stormwater runoff resulted in a 60-m-wide, 7-m-deep sinkhole directly below the road surface (Kambesis et al. 2004). Water and sewer pipelines in karst areas are also more susceptible to damage. When these pipelines do crack or break, the extra water pipes soil away more quickly, and new sinks may appear (USGS 1999). A dramatic example of this took place in Allentown, Pennsylvania, in 1994, beneath the Corporate Plaza Building, which was the city's newest downtown office building. The sinkhole opened up overnight and swallowed portions of the office building as well as the entire paved surface of North 7th Street immediately adjacent to the building. In this case, the cause of the incident was a natural soil sink that had been settling for at least several days prior to the event (occupants of the office building had reported evidence of subsidence during the preceding week, though it had not been recognized at the time); an overnight underground water leak accelerated the process and grew the sinkhole (Gillespie 1999).

Many of these same issues are found in karst areas that aren't even urbanizing. The need for vast amounts of groundwater can lead to rapid and excessive aquifer drawdown—and thus subsidence—in agricultural areas facing water pressures just as easily as in urban settings. For six consecutive nights in January 1977, strawberry growers in the Dover, Florida area, worked to prevent their crops from freezing by continuously applying warm water to their plants (this forms a protective sheet of ice over the plants and protects them from sub-freezing temperatures). The water used was pumped directly from the Floridan aquifer, and this sudden spike in groundwater pumping drew down the aquifer by 2.9 m. Reports of new sinkholes shot up; some of the new dolines were large enough to damage property and infrastructure. A total of 22 new sinkholes attributable to the freeze response were catalogued; others may have gone unreported (Hall and Metcalfe 1984).

Groundwater Contamination

In places with higher permeability bedrocks (like sandstone, for example), surface water must seep through the bedrock before reaching the water table. This natural filtration process is usually effective at keeping surface-level contaminants out of the aquifer. But because carbonate bedrock is not permeable, karst aquifers lack a filtration process for the surface waters that wash down through the cracks and fissures in the bedrock (sometimes, topsoil can act as a rudimentary filter, but it's not very effective) (Field 2002). As a result, aquifers in karst terrains are often left to the mercy and wisdom of the people who live above them. Unfortunately, wisdom doesn't always win out: the examples of aquifers in the Yucatan Peninsula, western Ireland, and southern China provided at the beginning of this chapter are just the tip of the iceberg; another example is the Apulia region of southern Italy, where the extensive karst systems have been severely degraded by an impressive array of anthropogenic factors (Parise and Pascalia 2003). Contributing factors to the destruction of all these aquifers were human-driven causes like overpumping of groundwater, deforestation, land drainage, agricultural practices and atmospheric pollution. It's true that such activities are often harmful regardless of where they occur; however, karst aquifers are particularly ill-equipped to handle the damage they can cause.

In many places, sinkholes and caves are often used as garbage dumps; this happens all over the world, from Turkey (Kacaroglu 1999) to the American Midwest (LeGrand 1984; Mitchem et al. 1988), and often leads to a rapid degradation in groundwater quality (Day and Reeder 1989). These contaminants often do not decompose or become absorbed into the aquifer. Many people assume that pollutants will be more rapidly flushed out of a karst aquifer, since groundwater moves more quickly through them than through other types of aquifers; this assumption is often wrong (Field 1992). Twenty years ago, karst professionals were lamenting that "attempts to explain the relation between sinkhole dumps and water supplies still often fall on deaf ears" (White 1988, p. 391). It is still a problem today.

Sinkholes do not have to be used as dumpsites to contribute to groundwater degradation. Because sinkholes can provide a direct passage into the aquifer for surface water and runoff, any contaminants picked up on the surface can quickly be carried into the aquifer. Sinkholes can also open directly beneath holding ponds or rivers and channel surface water directly into the aquifer below, as happened in Pinellas County, Florida, in 1988 and near Allentown, Pennsylvania, in 1979 (USGS 1999; Memon and Azmeh 2001). In the Pinellas County case, the sinkhole developed under an area containing heavy loads of effluent used for irrigation, and the Allentown sink was used as an industrial wastewater lagoon. Incidents of this type are extremely expensive to clean up, and in some cases remediation is simply not possible.

An even bigger potential problem is the development of sinkholes beneath landfills, especially in areas of active karst development where background studies have not been conducted. But even properly sited landfills and waste storage areas in karst areas can pose potential pollution problems. Precipitation or groundwater can mix with the garbage in any landfill, and then seep through the bottom, carrying with it bacterial and chemical pollutants that would quickly contaminate the aquifer (Davis 1997). Many municipalities in karst areas try to guard against waste-driven aquifer contamination by strengthening environmental requirements for landfills.

Large-scale agriculture has already been discussed as a cause of land subsidence in karst areas, but these operations often play a role in karst aquifer contamination as well. In most cases, the contamination stems from the use of nitrate-based fertilizers that are washed into the aquifer. One symptom of nitrate pollution is that water from nearby wells may have strange smells and a cloudy appearance. This type of contamination is common in rural areas—examples include the nitrate contamination of groundwater in Florida's Woodville Karst Plain (Katz et al. 2004), in the farming regions of northern Iowa (Mitchem et al. 1988), and in Romania (Gatzweiler and Hagedom 2003), where a decline in chemical fertilizer use since the early 1990s has not been followed by a corresponding drop in nitrate levels in the groundwater. In some locations, water from wells exceeds maximum allowable limits of pollutant concentrations, making the water unsafe for human or animal consumption. The fact that this degradation has persisted despite the decline in chemical fertilizer use illustrates the ability of pollutants to persist in karst aquifers. Similar contamination has occurred in the karstic lands of rural Appalachia, where the presence of nitrates in local well water has been linked to the so-called "blue baby syndrome" (Smith 2000).

Industrial land uses also pose major threats to karst aquifers. Mining—with its extensive use of chemicals and the likelihood of direct contact with the water table in some places—is an excellent example. Eastern Europe has experienced karst aquifer damage from mining operations, usually from careless disposal of waste materials. This is a particular concern in Romania's Apuseni Mountains, where mining has been a traditional economic activity for centuries (Turnock 2002; Forray 2002). Once again, the ability of groundwater to move quickly through karst aquifers is a major factor, as shown by the case of a Polish zinc-lead ore mine suffering contamination from paper factory fluid waste discharged over 5 km away in a karstic area (LaMoreaux et al. 1997).

Caves and Ecosystem/Habitat Damage

Of all the delicate karst environments discussed to this point, caves may be the most fragile. This is mostly due to their integrated nature—the overall health of the cave system depends on maintaining a precise balance between atmosphere, water, vegetation and soil factors. Obviously, direct human use of caves can result in alteration of the physical structure of the caves themselves, changes in the water chemistry or hydrology within the cave, or destruction of cave decorations and cave-dwelling organisms. But even human activities that do not involve the direct use of caves often have an impact on at least one of these factors in nearby cave environments. Dripwater flows are critical both to cave biota and to the microclimates of the caves themselves, and if those flows carry surface-level contaminants, the entire cave environment is affected. Any human activities that pose a potential threat to the aquifer—like, for example, careless disposal of wastes or excessive fertilization in agricultural areas—can have devastating impacts on cave life by altering the water chemistry (Watson 1997; Gillieson 1996). Though it rarely happens, caves can also be destroyed by aquifer drawdown, as sinkholes can form on the surface, collapse, and fill in the cave. It is usually not possible to restore a cave to its original condition after it has been degraded by human activity; for that reason, protection is a preferred strategy (Elliott 2005).

Ultimately, any processes that can alter soil composition, plant population and water flow patterns could have significant impacts on caves. Indeed, even modern cave-cleaning processes—used to remove dust and lint that accompanies humans into caves—can have a negative effect on cave development (Gillieson 1996). While the excessive groundwater pumping and heavy nitrate use, common to major agricultural zones, could easily upset the delicate balance of factors required for healthy caves, urbanization processes may be an even larger threat; not only are overpumping and groundwater contamination likely to occur, but construction activities may also redirect surface runoff flows in ways that can negatively impact caves and cave ecosystems. Developers and government sponsors of the Trimodal Transpark project near Mammoth Cave in Kentucky downplay the threat of the project by emphasizing the modern construction techniques designed to prevent contamination of the cave's headwaters, located a mere 13 km away. However, critics note that the project location was identified as the highest-risk area for contamination, flooding and collapse in the entire state. Even the government sponsors of the project—the InterModal Transportation Authority—cannot rule out contamination to the cave. As of this writing, the project is still on track (Brucker 2003).

The physical characteristics of karst landscapes render them extremely susceptible to damage and degradation. The demands of sustaining human settlements on karst are all but guaranteed to have some effect on these fragile landscapes;

however, whether out of carelessness or ignorance, humans have been abusing karst landscapes for centuries. In many cases human societies have suffered serious consequences as a result of the impacts of their own actions on the karst below them. It is possible that these impacts may sometimes be unavoidable. But if it is possible to avoid damaging the local karst system, what is the best way to go about it? The rest of this book will attempt to answer that question, with a focus on policy-based solutions to karst-related problems.

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Chapter 2
A Brief Look at Land Use Regulations in Karst Terrains

Abstract Karst regulations are in place in karstic areas throughout the United States, although the specific forms these ordinances take can vary widely from place to place. In seeking to understand how these regulations are developed and how they work, one must consider the possibility that they are influenced by factors that are tied to geographic location. This chapter examines this possibility by describing the regulatory goals of karst-aware land use regulations and ordinances, defining many commonly used tools for achieving these goals and exploring detailed examples of these regulations and ordinances from across the United States, grouped by region. The chapter finds that there do not seem to be strong regional influences on the development and character of karst land use regulations and it ends by identifying several characteristics that are widely shared by these regulations across the United States.

Keywords Setbacks · Stormwater runoff · Zoning · Land use regulation · Land use policy · Karst

The issues raised by human–karst interaction cut both ways: Human societies can simultaneously threaten and be threatened by karst landscapes. One way to manage this interaction and minimize the risks of subsidence, groundwater contamination and cave destruction is to regulate how construction, development and settlement can take place on karst terrains. In the United States, certain karst issues are often addressed via a state's administrative code (in many cases, the karst protections that are provided in this way are more of an afterthought or byproduct, usually in the course of setting rules for runoff management or dumping). But in many karstic areas with human populations, there are no municipal codes or ordinances that manage how humans and karst systems interact. While policy-based solutions have been successful in some locations, in others, land use policies have been less effective in protecting karst environments. In many cases, this failure is a result of lack of appropriate policy tools, weak or nonexistent enforcement, vaguely defined goals, poor conception or execution, or one of the other standard traps that often bedevil policy-based approaches. By their very nature, problems of human–karst interaction often require solutions derived from more than one field; however, local regulatory

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bodies often have more narrowly focused areas of responsibility that make the taking of an interdisciplinary approach difficult. Under those circumstances, organizations without any actual regulatory power—geological surveys, for example, or karst-related research institutes—can act as catalysts for policy-based solutions and as clearinghouses for the data required to shape such solutions (Vineyard 1976). There is no reason to assume that karst protection is inherently too complex an issue to benefit from a policy-based approach. However, many existing karst protection regulations have important flaws that hamper effectiveness.

Examples of Commonly Used Regulatory Tools

When policy protection for karst is implemented in the United States, it is often done through the zoning and land development approval processes. Because of the potential to impact flooding, surface and groundwater contamination, and sinkhole formation and collapse, municipalities certainly have an interest in enacting karst-related regulation. Different localities use different regulatory tools to manage growth in karst terrains, which makes sense in light of the differences in physical and social landscapes between individual cities and towns. However, there are several regulatory techniques that are used with more frequency than others: these include zoning codes, subdivision ordinances, stormwater management rules, and setbacks. Comprehensive plans also frequently address karst-related issues and, while they are a significant influence on land use decisions, they cannot by themselves be considered an effective tool for managing development in karst landscapes.

Zoning Ordinances

Generally, zones that include areas where threats to local karst formations are higher—or where threats *from* the local karst formations are higher—may be subject to certain additional construction requirements that are intended to mitigate that threat. These are often related to stormwater or surface water drainage and runoff or to implementing mandatory setbacks between human-built structures and karst landforms, usually sinkholes. In some cases, zoning overlays are used; this approach makes sense in cases where existing zoning laws would be difficult to change, or where the karst system spans multiple zones.

Subdivision Ordinances

Subdivision and land development ordinances (SALDOs) are commonly used to regulate development in karst terrains. However, because it is often easier for developers to get a variance from a SALDO, they are usually weaker forms of protection than zoning ordinances. In some places, the differences between subdivision ordinances and zoning ordinances are not clear; for example, both may be incorporated into a larger Land Development Code, particularly in smaller municipalities.

Stormwater Management Ordinances

In a karst context, stormwater management ordinances often forbid directing surface runoff directly into sinkholes and in some cases require a passive filtering system (gravel, wild grasses, etc.) be placed around the perimeter of a sinkhole near new construction or development. The popularity of stormwater management as a tool for managing development on karst landscapes seems to be an approach borne of practicality. Surface water is a source of contaminants and is simultaneously a contributing factor in sinkhole development; further, the consequences of poor or ineffective stormwater management practices are often highly visible, making it easier to build a political consensus to do something about it than it is with other karst-related regulatory tools.

Setbacks

Setbacks are another widely used approach to karst protection and land use management, though not as common as stormwater management. One advantage to the use of setbacks is that they are easy to understand conceptually, and theoretically require only a tape measure to enforce. However, they also make it more difficult for landowners to develop parcels with karst features (which often is the intent of the regulations in the first place); because of this, setbacks often come under heavy political pressure from developers or property owners who are seeking waivers or exemptions from setback requirements. One major shortcoming of the setback tool is that they generally only address sinkholes or, in some cases, springs. Contaminants can often find their way into the aquifer along other pathways (Rubin 1992). In other words, while setbacks may be effective in protecting human-built structures from subsidence dangers, they are not sufficient for protecting entire karst systems from human impacts. Some examples of communities using setback-style regulation can be found in Table 2.1.

Comprehensive Plans

Comprehensive plans are visible, high profile examples of local land use planning. Often, the development of a comprehensive plan is a process that incorporates significant community input and can take several years to complete.

Comprehensive plans are not discussed in this book. The reason is that their recommendations and goals are usually not binding; comprehensive plans typically

Table 2.1 Examples of municipalities employing setback-based karst land use regulations

Municipality	Setback size	Setback stipulations
Pasco County, FL	500 ft	Applies to new construction near karst features with the potential to drain directly into aquifer
Des Moines, IA	500 ft	Contaminated soil cannot be applied within 500 ft of a sinkhole
Amherst County, VA	200 ft	Hogs or chickens may not be kept within 200 ft of a spring
High Springs, FL	200 ft	50 ft. no-build zone, with the balance requiring guarantees of no damage to the sinkhole
Catasauqua, PA	100 ft	Applies to construction near any karst features within township limits
Lower Macungie, PA		
Lower Saucon, PA		
Alachua County, FL	35–150 ft	Setback size depends on specific nature of karst feature
Farragut, TN	50 ft	50 ft buffer applies to sinkholes only; aquatic buffer (25 ft) applies to springs
Huntsville, AL	25 ft	Applies to karst features throughout city limits
Godfrey, IL	25 ft	Stormwater mgt. rules applied to any land disturbance within 25 ft of a sinkhole
Maryville, IL		
Rome, GA	25 ft	Land disturbance buffer applies to all waters of the state; this includes springs. Protects karst, but not karst-specific
Savannah, GA		
Montgomery County, VA	20 ft	Route 177 Corridor zone requires a 20 ft setback from sinkhole edges
Springfield, MO	Outline of sinkhole	Applies to construction near any sinkholes within city limits
Lexington-Fayette County, KY	Outline of sinkhole	Applies to construction near any sinkholes within the county
Johnson City, TN	Varies	Applies in city's Sinkhole Overlay Zone; each sinkhole has a unique no-build line based on flooding potential

do not have the power of law. Because there is no power vested in comprehensive plans to compel developers and landowners to act in any particular way, they should not be considered a regulatory tool in this context.

State-Level Cave Protection Laws

Most states with any significant karst formations have passed law protecting these formations, to one degree or another, at the state level. These laws all tend to be very similar from state to state, at least in terms of the topics covered, if not in language. Cave vandalism is almost always the primary focus of these statutes, and selling speleothems that have been removed from a cave is almost always prohibited. Most of these laws contain provisions for protecting cave biota, while some of them contain detailed provisions relating to archaeological expeditions and digs; for example, Wisconsin's cave protection law is focused on protecting rock art in caves to the near exclusion of all other concerns. Language prohibiting dumping or polluting inside caves is also very common in these statutes, but these provisions are often worded in such a way that only polluting activities that occur within a cave are covered; only Missouri's and Oklahoma's laws might be interpreted to restrict polluting activities on the surface and nearby karst landforms. In some states, like Florida and Tennessee, state law provides homeowners the option of purchasing sinkhole insurance. In most states, however, insurance companies are not legally bound to offer this coverage.

Because the focus of these state-level laws tends to be on direct protection of caves from vandals and not on land use, they are generally not addressed within this book.

Examples of Policy-Based Approaches to Karst Protection

Karst-related land use regulations and ordinances have been used in the United States since the mid-1980s (Richardson 2003). These ordinances often focus on a single aspect of human–karst interaction, like imposing strict controls on new construction or management of groundwater inflow. At the same time, "multi-concerned" karst ordinances that focus on the impacts of new development on groundwater and the structural integrity of new buildings are becoming more common. Examples can be found in Johnson City, Tennessee, where an interim multi-concerned policy statement was adopted in 1994 (immediately following an extended period of excessive rainfall and flooding) (Reese et al. 1997), and in Austin, Texas, where a combination of land use management techniques and engineering controls are employed to protect the Edwards Aquifer from the consequences of urbanization (Butler 1987). Karst regulations are not universal because governments are often not given a sufficiently wide range of tools with which to manage karst. The available tools are typically limited to the comprehensive plan, the zoning ordinance, the subdivision ordinance, and the stormwater management ordinance. However, since the general public is largely unaware of karst and the planning issues that go with it, local governments are typically forced to handle karst issues in a reactive, rather than proactive, manner (Richardson 2003).

As human populations grow, so too do the challenges of waste disposal. As we have seen, the presence of karst can make disposal operations more difficult because of the inherent threat to groundwater quality. Requirements and regulations for handling the potential contamination of aquifers by landfills differ across the United States. For example, states take different approaches to defining both karst areas—only a handful specifically mention karst, while the rest use vague definitions of "unstable areas"—and landfills. However, there are minimum standards imposed by the U.S. Environmental Protection Agency (EPA); all landfills must have a groundwater monitoring system in place in the immediate vicinity of landfills, for one thing. At the state level, Florida regulations suggest a double liner for landfills but do not require one; Kentucky, on the other hand, does require the use of such a design (Davis 1997). The benefit of this approach is that regulations can be tailored to meet local needs; the drawback is that local political culture is more likely to influence the process and can potentially do so in a way that is not consistent with karst protection.

Policy-based approaches face even greater challenges when they are designed for implementation across multiple jurisdictions. The European Water Framework Directive, published in 2000, served as the catalyst for efforts to develop an effective and consistent European approach to groundwater protection in karst areas. The scientists working on this had the goal of integrating karst groundwater protection into the land use planning process throughout Europe. However, such integration had to be applicable to all karstic areas in Europe, which can vary greatly in terms of geologic and political conditions. Because of the difficulties in achieving this, they were forced to abandon the conceptual framework goal and instead attempt to develop a more general, common European approach to karst waters that was less comprehensive and less binding than they had originally intended (Zwahlen 2003).

Obviously, there is no one-size-fits-all approach to land use regulation on karst terrain. The remainder of this chapter examines regional differences in karst land use regulations in the United States, in order to identify any regional patterns or similarities in the types of karst-related land use ordinances in place. If those patterns exist, perhaps they can tell us something about the local and regional forces that shape the development of these regulations.

Appalachian Belt (Virginia, Pennsylvania, Maryland, New York, New Jersey, Eastern Tennessee and Eastern Kentucky)

Karst-related ordinances are common in cities and townships in Pennsylvania and New Jersey. Many of these ordinances were initially passed as a reaction to rapid expansion of residential development in the metro New York and New Jersey area since the 1970s. Specific motivations behind such laws differ – in some cases, it is a desire to limit population growth inside the town itself and to push new development to surrounding areas instead; in others, it is a desire to prevent groundwater contamination and to ensure structural integrity of new buildings; still others spring from a desire to reduce legal liability for karst-related damages. The North New Jersey Resource Conservation and Development Council (NNJRCD) Model Ordinance has been held up as an example of the type of regulation that works best to protect water resources and structures, without shutting down population growth and locking out new residents (Fischer 1997).

Indeed, karst land use ordinances based on the NNJRCD's model ordinance can be found in several boroughs and townships in northern New Jersey, including Franklin Township (Warren County), Lebanon, Lopatcong, Pohatcong, Vernon, and Washington Township (both Morris and Warren counties). The ordinance itself depends on the use of a Carbonate Area zoning district for areas where carbonate rocks or carbonate drainage can be found. Within these areas, additional karst-related data gathering and testing is required; this data shall be collected by direct means (site reconnaissance, test probes, test pits, and test borings) as well as indirect means (aerial photography and various geophysical methods). Once the data have been incorporated into the development plan, these geotechnical aspects are then subject to a separate review and, if found lacking, can serve as the basis for the denial of a permit. Failure to comply with the requirements of the model ordinance can result in a stop-work order, a necessary component if the ordinance is to have any effect at all. There are also many townships and boroughs that do not take the comprehensive approach to karst land use regulation provided by the NNJRCD's model ordinance. Nevertheless, many of these codes do still share at least one or two virtually identical passages, suggesting a shared source or origin. There are at least 23 municipalities (Table 2.2) that relied exclusively on this particular ordinance for karst land use management.

Pennsylvania's karst country extends across much of the southeastern part of the state. The frequency with which sinkholes occur there has spurred some cities and townships to draft legislation regulating the land development process in karst areas. This began in the late 1980s, when the township of Lower Macungie, near Allentown, incorporated a set of karst-related development regulations into the township's land development code. Lower Macungie is a township of about 24,000 residents in Pennsylvania's Lehigh County (population 326,000). It is important to note that in Pennsylvania, planning, zoning and subdivision responsibilities fall to local governments, rather than to counties or to the state. This makes it easier for localities to deal with any karst-related issues they may face, which are almost never replicated on a statewide level (and indeed, often not even on a county level). The ordinance relies heavily on the use of overlay districts to impose extra burdens on developers hoping to build in sensitive areas.

In drafting the Lower Macungie ordinance, existing ordinances in the area were examined by local government and outside consultants in order to identify provisions that were typically utilized by localities facing the same karst issues. Only

Table 2.2 New Jersey municipalities relying exclusively on the structural stormwater requirements of the NJ model karst ordinance

Alexandria	Holland
Andover	Hopcatong
Berkley Heights	Independence
Boonton	Jefferson
Branchville	Little Falls
Chatham	Madison
Clifton	Morris
Florham Park	New Brunswick
Franklin	Paterson
Glen Ridge	Rockaway
Hamburg	Sayerville
Hampton	

two other ordinances were found and both were subdivision ordinances. Both had serious shortcomings: one included too many restrictions on new development and was thought to be unenforceable; the other was not particularly detailed and likely unable to restrict development in karst areas. Another problem common to both is that they are subdivision ordinances, which are easier to overrule or waive than are zoning ordinances (Dougherty 1993).

Karst hazards are addressed in Section 794 of Lower Macungie Township's SALDO. In addition to establishing a local Karst Hazard Map, this section describes additional procedures and requirements that must be met as part of the Preliminary Plan process for developments in karst areas. They require the participation of a licensed geologist to determine what steps the developer should take in order to mitigate any threat to the local karst; those recommendations are then subject to review by the Town Engineer. The performance standards generally involve a 100-foot setback from any karst feature for proposed buildings, stormwater detention facilities, swales or pipes, septic systems or tile fields, swimming pools, solid waste disposal areas, transfer areas or facilities, oil, gasoline, salt or chemical storage areas, and or blasting for quarrying or well enhancement activities.

Beyond Lower Macungie, there are several other cities and townships in Pennsylvania's karst areas that have some karst-related ordinances on their books. Many of these are quite limited: Allentown's requires that the possibility of sinkhole existence be taken into account when creating a stormwater detention plan; Williams Township requires the disclosure of any karst features on property for which a grading permit is sought; and the extent of the city of Bethlehem's karst regulation is to require a bond from the developer intended to cover the cost of any sinkholes that form in the first year. Hanover Township's ordinance is not much stronger—it states that the presence or formation of a sinkhole under or very near a foundation or footing, the Building Official may withhold building or occupancy permits (if he or she feels the sinkhole poses a risk) until the developer explains exactly how that problem will be rectified. Other townships—like Catasauqua and Lower Saucon—have taken a more aggressive approach to regulating development in karst areas. Catasauqua's Code of Ordinances prohibit waste disposal in sinkholes if the property is accessible to the sewer system, and their Wellhead Protection Plan requires developers to minimize the risk of sinkhole formation through design techniques and adequate site planning practices. Additionally, the Wellhead Protection Plan prohibits the redirection of stormwater into a sinkhole, prohibits the alteration of drainage patterns through regarding if such alteration would increase sinkhole risk, and mandates 100-foot setbacks from karst features. Lower Saucon has taken the overlay approach implemented by Lower Macungie. Lower Saucon's zoning ordinance defines a Carbonate Geology overlay district which includes the following restrictions: on-lot sewer system drainfields, underground propane tanks, or stormwater control basins are to be kept a minimum of 100 ft from the rim of any depressions, sinkholes and disappearing streams and 50 ft from lineaments, fracture traces and pinnacles; outflow generated by the result of development cannot be directed into karst features; buildings or accessory structures must be 100 ft from any sinkhole, in most cases (likewise any toxic or hazardous substances); underground water, sewer and stormwater lines must have an impervious liner; most underground storage tanks are prohibited; and public sewers should be provided whenever possible and required—when they are not, applicant must provide a primary on-lot sewage system drainfield. There are also procedures in place for instances in which a sinkhole appears once approval has been granted.

Other karst-related provisions within land use regulations and ordinances predate the Lower Macungie ordinance. District Township has what might be the oldest karst-related ordinance in the area (passed in 1975), but it is also one of the weakest and most narrowly focused: it addresses permits for on-site sewage systems on property where sinkhole-related depressions exist within the absorption area.

While some regulatory techniques—like stormwater management—are used by rural and urban communities alike, some tools are seemingly intended to address issues more common to one type of environment than the other. Through a shared zoning ordinance, the rural communities of Heidelsburg, Womelsdorf and Robesonia impose setbacks on manure storage facilities not otherwise covered by state regulation. This is the only karst-related provision found in this zoning code and is one that is very unlikely to appear in the codes of more urbanized municipalities. Another regulatory tactic seen in rural areas is requiring setbacks for mining operations from sinkholes or karst features; in some cases, no other karst-related provisions are included. Some municipalities in the center of the state impose riparian buffers around sinkholes and require filtering mechanisms to prevent unfiltered runoff from running directly into a sinkhole (for example, Halfmoon Township), features that are not generally seen in ordinances passed in the Lehigh Valley region.

Karst-aware land use regulations are also present in Maryland, but often seem open-ended and vague; there also seem to be fewer of them than in Pennsylvania. Overlay-style karst management techniques are used in smaller towns like Hampstead and New Windsor. In New Windsor, for example, developments in areas of carbonate rock are required to incorporate design elements that are intended to accommodate the geological conditions. This is very similar to the way Taneytown approaches the issue, requiring subdivisions be designed in such a way that environmental resource areas (including areas of karst geology) are protected. The presence of these environmental resource areas must be included in certain plans during the pre-approval process. In Hagerstown, the city code stipulates that the presence of karst geology shall guide the selection of best management practices for stormwater drainage techniques. However, specific methods for accomplishing this are not identified, and developers and builders have significant leeway.

By contrast, karst regulations in Virginia strongly emphasize informational requirements and setbacks. By far the most common karst-related land use requirements in Virginia are for the disclosure of sinkhole and spring locations at various points during the permitting process: Alexandria requires such disclosure during the environmental site assessment for resource protection areas; Blacksburg requires it during the development of the stormwater management plan; and both the city of Roanoke and Franklin County stipulate that this information be included on the comprehensive site development plans themselves. In most cases, karst-related setbacks are related to agricultural land uses, like the location of swine facilities or chicken plants. Radford, Waynesboro and Montgomery County are exceptions to this, with more broadly applied setback/no-build rules. Montgomery County's Route 177 Corridor Overlay District stipulates a minimum 20-foot setback from the edges of any sinkholes that occur there. In Radford, no land with sinkholes or caves can be platted for subdividing, due to flooding concerns, while these same lands are simply described as "unsuitable" for construction in Waynesboro. One interesting thing about Virginia's karst-aware land use regulations is that many places outside the state's western karst belt also seem to have them on the books. Springs are the most commonly mentioned karst feature to be protected; this could be because the regulations in question are meant to apply to all watercourses, regardless of whether or not they are actually present in the area (hence, springs are mentioned in some areas' ordinances as features meriting protection even though they are not actually found there).

Virginia has also taken steps to proactively address karst issues at the state level. The state's administrative code created the Cave Board, an office within the Department of Conservation and Resources that is tasked with cave policy development and enforcement. The state code also bans construction of landfills atop sinkholes or less than 100 ft above karstic caverns and prohibits discharging into springs or sinkholes.

Johnson City, Tennessee, employs setbacks in an unusual way. The setbacks only apply within the city's Sinkhole Overlay Zone, which was implemented as part of a larger set of floodplain regulations as a means of addressing flooding and groundwater contamination concerns. Within the overlay zone, development near sinkholes is constrained by a "25-year no-build line," which differs for every sinkhole depending on its capacity to handle runoff from a major rain event. Generating a unique line for each sinkhole requires a high level of understanding of the local drainage system and is an exacting process. The code does contain provisions for altering the location of these lines, if necessary. Additionally, zoning appeals board can consider requests for variances within both zones. Farragut (a suburb of Knoxville) has a fairly well-developed set of setback rules, which generally mandate a 50-foot buffer from the edge of any sinkhole; a different buffer (25 ft) applies to springs. Outside Farragut, Knox County itself employs setbacks in a much more limited fashion, applying them only to landfill siting. The city of Knoxville permits land containing sinkholes to be platted and developed only if the developers have taken steps to eliminate the potential for sinkhole-related flooding damage to buildings and other structures. The specific nature and character of these "steps" is never clearly spelled out.

Southeast (Florida, Georgia, South Carolina)

Karst regulations in Florida are extremely common in local governments of all sizes, from large urbanized county governments to smaller, rural communities. There is no single dominant method of regulation: overlays, setbacks, stormwater runoff and drainage and basic informational requirements are all employed throughout the state. That said, there are several areas in which karst-related land use regulation is stronger or better developed than most other cities or counties; examples include Alachua County, Leon County, and Marion County.

Alachua and Leon counties are very similar in many ways. Both contain mid-sized cities (Gainesville and Tallahassee, respectively) alongside large stretches of undeveloped, rural land, and in 2000 both counties had similar populations (217,000 and 239,000, respectively) (U.S. Census Bureau 2006). These similarities suggest that both areas might take similar approaches to karst land use management. In both counties, we see city and county regulations working in tandem to manage different aspects of the development of karst lands. Alachua County's regulations emphasize the control of stormwater runoff as an approach to karst terrains development: stormwater management systems must provide treatment to sinkhole runoff before discharging it into a sinkhole and must be designed in a way that minimizes the risk of new sinkhole development. In some cases, wastewater may not be discharged into sinkholes at all. Additionally, the county does impose a setback around karst features, covering anywhere between 50 and 150 ft, depending on the specific characteristics of the feature in question. Within the city of Gainesville, environmental overlay zones are the primary tool for managing development on karst: the city's Significant Ecological Communities environmental overlay zone is used to protect sinkholes. Within these overlay zones, the city has the right to set aside up to 10% of a lot's area in order to facilitate clustered development that would protect the ecologically sensitive features.

In Leon County, there is somewhat more overlap between city and county regulations. Both the county and the city of Tallahassee apply an identical conservation area regulatory overlay to lands with active karst features. Within this overlay, all uses permitted by the underlying zoning classification are still permitted, with the additional stipulation that uses must be "compatible with the environmental conditions," and thus subject to additional restrictions if necessary (additionally, off-site density transfers are not permitted within the conservation area overlay). The city and county both use setbacks as well, though they are applied differently in each jurisdiction. The county's setback regulation (which does not actually use the word "setback") requires any active karst feature to be surrounded by a 35-foot buffer, inside which the land will remain in a natural state. Tallahassee's no-build requirement is nearly identical to Gainesville's in that it mandates that any land with karst features be given over to the city in the form of a conservation easement. The city also has detailed regulations on how stormwater runoff may be handled in karst terrains.

Historically, Marion County has maintained a more rural character than Alachua or Leon counties. Located just south of Alachua County, in recent years Marion County has been undergoing rapid urbanization. Marion County is unusual among Florida's rural areas in that it employs overlay zones as a means to control growth in karst terrains. The county's Environmentally Sensitive Overlay Zone (ESOZ) is applied to many of the area's springs; like the overlays used in Alachua and Leon counties, Marion County's code states that within the ESOZ all requirements of the underlying zone apply, with the added stipulation that development or usage cannot impair or diminish the condition of the natural features. The ESOZ also requires larger minimum lot sizes (1 acre) for any new developments, as well as 75-foot setbacks from water bodies, including springs. Setbacks are also applied outside the ESOZ: residential developments must be set back 50 ft from any sinkhole edge, while non-residential land uses cannot be closer to a sinkhole than 200 ft.

Florida is one of the most populous states in the country and is home to several major metropolitan areas. Orlando's approach to karst land use management stands out among these large cities in that it uses an environmental overlay to protect karst features. The overlay mandates the inclusion of more open space in developments in karstic terrains, implements a cap on the impervious surface ratio, and requires the use of best practices in managing stormwater and golf course runoff as well as the generation of an environmental assessment that details the locations of all sinkholes and springs in the area. This stands in contrast to other larger cities like St. Petersburg or Tampa, where no similar regulations are found: in Pinellas County, sinkholes cannot be considered as adequate positive outfall for runoff from new subdivisions, while Hillsborough County regulates runoff in wellhead protection areas and forbids excavations and landfills from sinkhole-prone areas (though it should be noted that sinkholes are historically less of a problem in Pinellas County than in central Florida).

On the other end of the spectrum, many of Florida's rural counties and towns have basic karst protection on the books; however, it is often not quite commensurate with the amount of karst that underlies the municipality in question. Citrus County, for example, seems only to require a 300-foot setback between sinkholes and domestic septic systems, despite the high number of caves and sinkholes found there. Brooksville requires only the inclusion of karst landform information on various plans and maps; Lake Mary requires such information only on the drainage plan. Leesburg's code forbids landfills from being located in sinkhole-prone areas. Levy County requires a geologic analysis for any development over five acres in size, or for any development located in sinkhole-prone areas; however, there are no other restrictions spelled out in the county code. The small Central Florida town of Casselberry explicitly reserves the right to address karst-related issues on a case-by-case basis.

However, a hands-off approach to regulating the use of karst lands is not universal among rural communities. Some are more aggressive in controlling their karst problems. Inverness reserves the right to declare a plot of land unsuitable for development because of the presence of sinkholes. Pasco County's code grants Special Protection Area status to karst features with the potential to drain directly into the aquifer; that designation includes a 500-foot setback from the edge of the feature, which was the largest setback found in the state. Neighboring Hernando County takes a similar approach by granting protected status to sinkholes and caves found within the county's designated wellhead protection areas; both Pasco and Hernando Counties regulate runoff and discharge into sinkholes as well. High Springs, a rural community in Alachua County, employs a set of well-developed setback regulations. Lands within 200 ft of a sinkhole edge are considered to be in a development constraint area. This includes a 50-foot no-build zone, with any development occurring within the remaining 150 ft requiring professional certification that no damage will occur to the sinkhole as a result of development. Beyond that, it is also not permitted to direct stormwater runoff straight into sinkholes.

Communities in karstic areas of Georgia tend to rely on either overlay districts or setback ordinances for karst land use management. Auburn, Bainbridge, and Norcross are all examples of towns that rely on groundwater recharge overlay districts for this purpose; these districts are intended to protect "significant recharge areas" (a definition that includes karst landforms) from the negative impacts of human activity in the recharge zone. Of these three examples, Norcross' ordinance is the most comprehensive: development density is limited within the recharge overlay district and is generally controlled by the imposition of larger minimum lot sizes. Further, "dangerous" land uses such as landfills or waste dumps are prohibited from being sited within the overlay; design standards are also employed to manage the impact of the development that does occur there. Bainbridge's ordinance is similar, but is more limited in its application: only residential developments where septic systems will be used are subject to the larger minimum lot size requirements. By contrast, Auburn's overlay does not restrict development or density at all within the groundwater recharge zone, but is instead solely concerned with the dumping of contaminants.

South-central (Kentucky, Tennessee, Northern Alabama, Missouri)

Throughout the south-central region, stormwater runoff and informational ordinances are commonly used as means of controlling development on karst. Some localities go a bit further and rely on setbacks. These setback ordinances are not uniform, with the most significant differences being the minimum distance between land disturbing activities and the sinkhole edge. Overlay districts are employed in smaller cities like Germantown, TN and Danville, KY; Danville's overlay specifically includes sinkholes as part of an ecological hazard district, while Germantown's wellhead protection overlay applies to—but never specifically mentions—karst landscapes. Regardless on the methods used, the goals are often related to flood prevention more than aquifer protection. Throughout the region, ordinances tend to be implemented primarily at the city level, as opposed to the county level.

Karst-aware land use regulations in many Kentucky cities and towns—like Bowling Green, Madisonville, Mayfield, and Murray—focus on controlling the accumulation of sediment in sinkholes. This suggests that flood control is the primary concern of these regulations, since too much sediment in a sinkhole can clog its drain. Indeed, stormwater and flooding problems were the initial driving force behind Lexington-Fayette County's sinkhole ordinance. In 1985, the Lexington-Fayette government passed an ordinance to regulate development with respect to sinkholes, karst features and their associated groundwater flow systems. This was in response to the revelation that many stormwater problems in the areas were caused by development in close proximity to sinkholes. The 1980 comprehensive plan contained the first serious attempts at regulating development in sinkhole areas in the Lexington region, but was eventually found to be too general to effectively manage development in karst areas. The 1985 ordinance rectified this problem by providing a definition of sinkholes, identifying specific maps for use in the field determination process, identifying specific types of testing and studies that must be done prior to development (as well as who is capable to perform them), and laying out acceptable modes of development near karst features (Dinger and Rebmann 1986). Opinions differ on whether or not the Lexington regulations have been effective; residential development still occurs on lots adjacent to those which are rendered unsuitable for construction by the presence of karst features and because residential lots are on average smaller than they were when the ordinance was first passed, impact on the karst system is not especially unlikely (Rebmann 2006).

Most of Alabama's karst is found in the northern part of the state, with another belt stretching through the middle and running to the northeast. The city of Huntsville is located in this northern karst belt. Huntsville's approach combines simple information requirements with actual setbacks: descriptions of all karst landforms and their locations must be included in various planning documents and the city code mandates a 25-foot setback from the edge of any sinkhole for all new construction. This restriction is applicable citywide, but is also specified in the development requirements of the city's slope development district. Nearby Muscle Shoals' ordinance is clearly designed with flooding issues in mind and takes an unusual approach in addressing them: the ordinance stipulates that no construction can occur in a sinkhole floodway, unless the developer removes a volume of material from the floodway that is equal to or greater than the volume of the structure erected in the floodway—in other words, no net loss of volume can occur as a result of construction.

In contrast to communities in the eastern part of the state, karst-related land use ordinances in central and western Tennessee are more similar to those found in Kentucky that try to prevent sewage or sediment from draining directly into sinkholes. Towns like Brentwood, Clarksville, and Colliersville do not go beyond this basic level of karst protection. Germantown was mentioned earlier as an example of a town using overlay districts; the nearby city of Nashville, on the other hand, employs no karst regulations whatsoever.

The fast-growing city of Springfield, Missouri, passed an ordinance in 1989 to more effectively manage the increased stormwater runoff that was a consequence of the rapid urbanization and population growth in sinkhole drainage areas. Prior to the ordinance, one method commonly used to control stormwater runoff in karst areas was to simply drain directly into sinkholes, which carried with it the possibility of introducing contaminants into the aquifer. The ordinance required that developers obtain an additional permit for projects proposed within sinkhole drainage areas; the permit application must address various geologic and structural issues to the satisfaction of the permitting authority before construction may proceed. Other places in Missouri, including rural Stone County, have embarked on similar projects; Springfield's experience points to potential shortcomings in their own approach, including the description of enforcement procedures and an oversimplified understanding of the spatial patterns of urban growth in the Springfield area (Barner 1999; Barner 1997). Jackson is another Missouri city that relies on setbacks or no-build areas to prevent damage to the local karst. In Jackson, any sinkholes on land undergoing subdivision will be given easements as a means to protect the landforms from human encroachment.

Throughout Missouri, it is not uncommon to find stormwater-related karst regulations that are very narrowly focused. St. Louis County forbids the installation of sewage tanks or soil absorption systems in the drainage area of a sinkhole, while Ballwin specifically permits sinkholes to be used for drainage as long as there is an outfall pipe installed (in case the sinkhole cannot handle the excess runoff). Hannibal exempts one- and two-family residential developments from the requirements of the onsite stormwater management plan, unless the development adversely impacts a sinkhole; in that case, the plan is required. In most other cases, the only requirements relating to karst are for information about location of sinkholes or springs and in some cases even those requirements are limited to very specific circumstances, like the location of sanitary landfills.

Great Lakes (Indiana, Illinois, Iowa, Minnesota, Wisconsin, Ohio)

Here, karst-related land use regulations tend to be focused on either information requirements or stormwater management and drainage. Aquifer protection seems to be a stronger focus here than in, say, the south-central region: there are more regulations specifically mentioning sewage discharges, bio-solids or contaminants from construction sites draining into sinkholes, as well as limitations on the use of septic systems in certain areas. When setback regulations are found, they are often very narrowly focused, usually related to the placements of human or animal waste facilities. Regulations and ordinances seem to exist mostly at the city or town level and are less common at the county level.

Indiana's regulations are almost exclusively information requirements or related to stormwater runoff and don't include anything not discussed elsewhere in this chapter. One interesting characteristic of Indiana's karst-aware land use ordinances is that many, if not all, of the karst provisions are identically worded, strongly suggesting that most towns are working from the same basic set of templates. This is not all that surprising, really—it suggests that these provisions have been found to be legal or are thought to be most likely to be able to withstand court challenges in the future.

In Illinois, the more comprehensive karst-related land use regulations are found in towns located in the southwestern part of the state, just east of St. Louis. This is the location of one of Illinois' two large karstic zones. Here again, one sees a great deal of repetition in karst regulations between towns. Maryville and Godfrey, both near St. Louis, have several identical components to their karst-aware land use regulations; these include the requirement that stormwater not be redirected into a sinkhole, or that stormwater drainage basins be set a minimum of 100 ft from a sinkhole edge. Both towns also mandate that “special precautions” be taken to prevent damage to sinkholes as the result of necessary development activity. As in many other locations, neither “special precautions” nor “necessary development activity” are explicitly defined.

Municipalities in the northern Great Lakes seem to rely on setbacks more frequently than in Indiana or Illinois; these setbacks generally relate to facilities for storing human or animal waste. In southwestern Wisconsin, landowners will adjust their own land use strategies to conform to the presence of sinkholes, even in the absence of local regulations or ordinances. Generally they are left alone, though in some cases they are used for waste disposal, as the waste often fills a secondary purpose of providing infill material for the sinkhole (Day and Reeder 1989). Oddly, in many Wisconsin communities, areas near karst features are specifically *prohibited* from meeting city runoff requirements. These runoff requirements generally include a reduction in the total amount of suspended solids and attempts at recovering as much of the preconstruction infiltrate runoff as possible.

Fillmore County, Minnesota, provides a representative example of sinkhole ordinances in this part of the United States. Fillmore County is a rural farming community in the southeastern part of the state. Sinkholes have long been a problem there, with a high concentration of them running along an axis from the northwest to the southeast of the county. The passage of the Fillmore County sinkhole ordinance in 1989 was the result of a conscious effort to update and strengthen an ineffectual ordinance that originally dated back to 1971. During the 1980s, residents had grown more conscious of environmental issues, including the groundwater contamination issues that go hand-in-hand with living on a karstic landscape. Residents often voiced complaints about the practice of waste dumping in sinkholes in public meetings, which eventually led to the hiring of an outside consultant to rewrite the ordinance. The updated ordinance is typical of sinkhole ordinances throughout the rural midwestern United States, in that it focuses less on building and development restrictions and more on dumping and pollution issues. The ultimate goal of the ordinance is simply to keep sinkholes clean and free of trash, especially hazardous materials.

The practice of dumping wastes in sinkholes had a long history in Fillmore County. Sinkholes were at one time widely used for wastewater disposal; local residents would use dynamite to open the bottoms of the sinkholes in order to drain the human waste away. The town of Harmony was once the source of a flu outbreak that was initially driven by the contamination of area sinkholes. Disease-related issues led local lawmakers to look at sinkhole and karst-related issues over the years; however, local environmental planners say issues like these are more of a historical relic and are much more rarer today. This could explain why the driving issue behind rewriting the ordinance was not public health, but quality of life: garbage-filled sinkholes dotting the landscape were considered to be unsightly eyesores, and residents wanted something done about them.

The project to rewrite and strengthen the 1971 ordinance had broad support, both inside and outside of local government. According to the county's senior environmental planner, there were no obstacles at all to passing the ordinance, since "nobody had the courage to publicly argue in favor of dumping in sinkholes." As a result, the county's planning commission and board took an aggressive stance on the ordinance and quickly completed both the rewriting and approval processes. This cycle included "3 or 4" public hearings intended to solicit the input of local residents.

Fillmore County has made significant efforts toward public education on karst and sinkhole-related issues over the last 20 years. The county's senior environmental planner said he has "lost count" of the number of public education campaigns the county has undertaken during that time, but believes that this commitment to karst education has helped get residents on board. During the early stages of development for the ordinance, a number of other approaches were considered, including the use of setbacks. These had already been implemented by the local water conservation district and were therefore not unfamiliar to local lawmakers. However, their use for sinkhole protection was rejected; the high price of corn and beans—two of Fillmore County's major crops—made it difficult to justify leaving otherwise productive land unplanted. Plugging sinkholes was apparently never seriously considered as an option, due mainly to the large amounts of fill material that would be required for a sinkhole-pocked landscape like Fillmore County's.

When asked about the effectiveness of Fillmore County's sinkhole ordinance, the county's senior environmental planner says that he believes the ordinance has had a positive effect, but admits that he has no real way to quantify that impact. However, he does point to a decrease in resident complaints about dumping in sinkholes since the ordinance was implemented as evidence to support his claim; visual sightlines are also less cluttered by piles of debris in open fields. He also credits state and county programs—including a pesticide container clean-up program that gave farmers an alternative to dumping pesticides into sinkholes on their property, a county-level white goods recycling program, and increased enforcement of dead animal disposal violations by the Minnesota Pollution Control Agency—with helping to instill an awareness of the environmental problems caused by trash disposal in sinkholes (Craig 2008).

Large piles of trash and waste in sinkholes are very visible to the general public and are therefore likely to attract negative attention. This is a theme that is repeatedly seen in municipalities that choose to regulate land use on and near karst features: when a karst-related problem has a high public profile, it is much easier to mobilize the political will necessary to impose appropriate land use restrictions. It is possible that without such a high level of visibility, the problem in Fillmore County would not have been viewed as something serious enough to merit attention. Indeed, it seems that there are limits even on high visibility karst threats, like trash-filled sinkholes, in their ability to drive regulation-based solutions. For example, the approach that Fillmore County eventually took left the local water table susceptible to nitrate contamination from the commercial fertilizers used in the local agriculture community, out of a desire to maximize the local crop yield. Clearly, the perception of the possibility of economic loss can have a major impact on the form and strength of any karst regulations passed.

The West

Karst-aware land use regulations and ordinances are less common in the western United States. This is likely due to a number of factors, including the lower population densities, the more scattered distribution of karstic lands, the fact that so much of it is paleokarst, and the so-called "western ethic" of land use regulation. However, there are still isolated instances of karst land use regulations. Moab, Utah uses drinking water protection zones that mandate tighter restrictions on development as it gets closer to the wellhead. However, in no case is building and development completely forbidden within a protection zone; instead, discharges of pollutants or contaminants themselves are regulated and controlled. In Santa Fe, New Mexico, density transfers are suggested—but not mandated—as a method of protecting springs.

Austin, Texas provides a stark contrast to the prevailing western approaches to regulating karst land use. In Austin, increasing rates of urbanization had begun to seriously threaten the karstic Edwards Aquifer by the early 1980s. In response, the city enacted a series of ordinances and regulations that approached the issue of aquifer contamination from several different angles. These included the management of stormwater runoff with additional engineered solutions, the development of a three-tiered watershed zone system designed to manage the types and intensities of land use along waterways within the watershed, and the ability to transfer development rights (and therefore shift land use intensity) from the Buffer watershed zone to the Uplands zone, where development is less likely to negatively impact the karst aquifer (no development is permitted within the watershed's designated Critical zones) (Butler 1987).

In the early 1980s, Austin city officials began implementing watershed regulations intended to address water supply and quality issues in the western and southwestern sections of the city, where a large number of lakes, springs, and city reservoirs are located. These regulations were well-intentioned but suffered a major flaw: while they did require an assessment and identification of karst features on property to be developed in those areas, there was no mechanism in place to protect these landforms once they were identified, which meant that the overall amount of actual protection provided by these ordinances was low. After several years of attempting to protect the local aquifer using this patchwork approach, in 1986 the city adopted a comprehensive watershed ordinance that brought all of these regulations under one umbrella.

This newer ordinance included provisions for protecting "critical environmental features." Under the terms of the ordinance, karst features qualify for this designation and therefore received setback-based protection. These setbacks were set at 150 ft, with the condition that they could be expanded up to 300 ft in areas located upstream from any significant recharge feature as a means of protecting the feature's drainage area. Environmental assessments are still required to identify and evaluate all karst features on a parcel intended for development. City staff review the information derived from these evaluations—which are provided by the developer or property owner—for accuracy and completeness. Staffers indicated they sometimes experience problems obtaining high-quality information from these applications. Part of the problem can be attributed to simple professional disagreement, based on different interpretations of scientific data. There are also some consultants who may favor development over conservation, and their reports may reflect that bias, either consciously or not.

In 1992, the Save Our Springs ordinance was first passed after a citizen-driven grassroots effort to place it on the ballot as a referendum. The ordinance was written to specifically address water quality issues in Barton Springs—which draws directly from the Edwards Aquifer—by mandating low impervious cover levels and forbidding the release of pollutants within the spring's recharge zone. Barton Springs takes in surface water from a 360-square mile area; that water perks through the ground rapidly and emerges at the spring, and research conducted by city staff demonstrates that the area does not have a high capacity for removing pollutants or filtering. The ordinance uses both land use controls (specifically, mandates requiring low levels of impervious cover of 15–25%) and engineered non-degradation water quality controls together. Common sentiment around Austin is that the city should not rely completely on engineered controls for water quality protection, because there is always some risk of failure in any engineered control. This approach addresses that shortcoming. However, city staffers still see continuing attempts by developers to argue that they shouldn't have to adhere to impervious cover limits because their engineered solution is more than adequate to mitigate the risk. It is also apparently common for them to argue that restricting impervious cover below 45% amounts to a taking; they believe they should be compensated for protecting the aquifer in those cases.

At about that same time, endangered and protected species were first identified within the spring and the aquifer itself, like the Barton Springs Salamander, first recognized as unique to that location in the mid-1990s and listed as endangered in 1997. The presence of these species adds a layer of complexity to karst protection regulations in Austin, thanks to the federal Endangered Species Act. Additionally, there are some state-level regulations in Texas that address karst issues; however, Austin's ordinances are much more restrictive.

The city of Austin often relies on negotiation with local landowners and developers to maximize the level of karst protection it is able to provide. This often occurs in the course of large-scale legal settlements and generally involves the delineation of setbacks for specific karst features. In negotiating these setback sizes, the city has two goals: to control the amount of surface runoff and to protect the subsurface footprint of any caves located below. In some cases, identified karst features in upland areas are geologically relic features that may have once taken in significantly more drainage than they currently do. As a result, their drainage areas are smaller and larger setbacks are not generally required. These smaller setback sizes can then be offered to landowners or developers in exchange for larger setbacks around nearby karst features that are more active and handle larger amounts of runoff. In other cases, the setback buffer may be decreased on the downslope side of a karst feature—where water is unlikely to drain into the feature—in exchange for a larger protection buffer on the upslope side. In other cases, the city has taken a different approach to negotiation and has instead opted to use development agreements as a means to establish karst preserve areas for locations with significant karst features. In this way, Austin is able to keep these features in their natural state.

One shortcoming of the regulatory approach to karst protection in Austin is that the city itself only controls about one-third of the Edwards Aquifer drainage basin. The rest is controlled by other municipal jurisdictions, but is mostly under the same high levels of development pressure that face Austin. Unless these lands can be brought under an adequate karst protection regime, all the efforts of the city of Austin to protect the aquifer and Barton Springs could be for nothing. To address this, the city has been able to convince voters to approve bonds to buy up parcels of sensitive land that are actually beyond Austin's legal jurisdiction; the city then places these lands into easements or preserves. To date, the city has used this approach to obtain control of about 25,000 acres of sensitive land in other nearby municipalities. Austin has also capitalized on an increasing awareness of karst-related issues and a desire to preserve the natural character of some of these landscapes in surrounding cities and towns to drive a regional planning effort aimed at developing some level of regional cooperation on these issues. Many of these cities and towns are also trying to restrict new development as a means of protecting local resources and are beginning to see the advantages in taking a region-wide approach to the issue.

Austin's environmental officials credit the city's progressive political culture and strong support from the community in general—and citizen-driven environmental activist groups like the Save Our Springs Alliance and the Save Barton Creek Association in particular—as being central to their ability to take the aggressive approach to karst protection that they have used over the last fifteen to twenty years. In the words of one Austin city official, "the ordinance we have in place now was the result of the culmination of years of frustration on the part of local environmentally-minded citizens." The period from the late 1980s to the mid-1990s was dominated by political wranglings, back and forth between developers and environmentally minded constituents. As mentioned earlier, the first set of real comprehensive karst-related regulations for Austin came in 1986 with their comprehensive watersheds ordinance. The next significant effort to regulate impervious cover levels came a few years later in the early 1990s, initially with an interim ordinance called the Non-Degradation of Barton Springs Act. This ordinance dropped impervious cover levels in the relevant area to as little as 18% of land area. Almost immediately, there was a pro-development reaction that managed to undo the impervious cover level changes. However, these tactics backfired on the development community when they actually acted to spur community activism against a majority pro-development council. Ultimately this led to the citizen-driven ordinance known as the Save Our Springs ordinance, which was approved by voters as a referendum but lost an initial court battle. It was upheld on appeal several years later, in 1996.

However, that does not mean that acceptance of these regulations has come easily. Interference and resistance from both the local construction and development community and from state-level elected officials have slowed the process and resulted in weaker protections than city staffers would have liked; almost every year, there are attempts by state government to undo the progress of the city of Austin in protecting its local environment. In the early 1990s, the Austin development community was successful in getting exemptions from the new laws; one city environmental official estimates that roughly 85–90% of all development projects during this time were "grandfathered" into an exemption from these regulations (eventually, many of these projects were brought under the umbrella of Austin's karst protection via negotiated development agreements). The state of Texas also has a grandfathering statute that allows people to develop under the regulations that were in place when the project was first started, which in some cases could have been decades prior. Takings and property rights approaches are the most common tools used to try to roll back the Austin regulations and these happen every year.

In the interim, the Austin City Council's stance on environmental issues has become greener than it was in the early 1990s. The Save Our Springs ordinance is now an accepted part of the local regulatory landscape; there are no lawsuits or court battles involving the ordinance and most of the area's big landowners have negotiated agreements with the city. The larger threats that remain come from developers going outside the city's jurisdiction, but as was mentioned earlier, the city is taking steps to address those developments as well (Murphy and Johns 2008).

Summary

Table 2.3 provides a summary of the most commonly used regulatory techniques in each region. From the data presented in this chapter, we can draw several important conclusions about karst regulation in the United States:

1. Regulations seem to display more within-state similarity than within-region similarity. This suggests that municipalities may be more concerned with implementing regulations that will withstand legal challenges within their own states than they are with the specific physical nature of the karst system below (because these systems often cross state lines, we would expect to see strong within-region, interstate regulatory similarities if the strongest driving factor was the physical characteristics of the karst itself). The one exception to this is the case of Tennessee, in which communities in the eastern part of the state tend to take a more proactive approach to managing karst problems through regulation.
2. There does not seem to be any relationship between levels of urbanization and regulatory methods used, or indeed between urbanization and the existence of karst regulations or ordinances. Several large, highly urbanized areas on karst—Tampa, Florida and Nashville, Tennessee are good examples—either have rudimentary karst protections on the books, or none at all, while some rural locales (for example, High Springs, Florida) have taken a much more proactive approach to regulating development on karst terrains. However, it is difficult to argue that there is an inverse relationship between government sophistication and regulatory sophistication, since urban areas like Lexington, Kentucky and

Table 2.3 Most commonly used regulatory techniques in each region

Region	Dominant regulatory techniques
Appalachian belt	Setbacks; stormwater management; extended pre-development review requirements
Southeast	Stormwater management; setbacks; overlay zones
South-central	Stormwater management; informational requirements
Great Lakes	Stormwater management; informational requirements
Western U.S.	Groundwater protection

Huntsville, Alabama also use the regulatory system to manage development on or near karst landscapes; likewise, there are many examples of rural communities in karst terrains where no regulatory mechanisms exist.

3. Stormwater runoff is a very common way—indeed, perhaps the most common way—to regulate land use in karst areas. Possible reasons for this are explored in the next chapter.
4. Overlay zones, while not widely used, are applied in rural settings as well as urban areas. This is surprising, as it seems reasonable to assume that the lower demands and pressures on rural lands should not require a regulatory tool as blunt as an overlay zone.

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Chapter 3
What Planners and Land Use Professionals Understand About Karst

Abstract Developing a comprehensive understanding of the impact and effectiveness of karst-related land use regulations requires accurate knowledge of what these regulations actually do and how they work. To that end, land use planners and related professionals in six states were surveyed regarding their knowledge, understanding and opinions of karst-related land use regulations in their local areas. The survey's questions touched on six broad themes in karst protection regulation, including karst knowledge in the planning community, pervasiveness of karst regulations, preferred regulatory techniques, the motivations that drove implementation of these regulations, the influence of different stakeholder groups on the process, and the overall effectiveness of the regulations. This chapter describes and analyzes the results of this survey and makes several recommendations regarding karst-related land use regulation based on the responses of survey participants.

Keywords Land use planners · Karst land use regulation · Opinions and attitudes

The first step in developing a full understanding of karst-related land use regulatory issues is to read up on actual regulations and ordinances in use across a variety of karst terrains, which was done in the previous chapter. But this is only the first step. Without knowing how these regulations interact with conditions "on the ground," any understanding will be incomplete, a half-measure at best.

We simply must understand the impacts these regulations actually have on the communities that use them, as well as the factors that affect the development of the regulations in the first place. Many relevant questions about the impacts of these regulations have yet to be thoroughly explored and answered. Do setback ordinances affect housing or population densities in areas where sinkholes are common? Do karst ordinances scare off new development and growth opportunities? Which stakeholders tend to have the loudest voices or the most influence when regulations are being written? These questions, and others like them, must be answered before any useful framework for understanding and developing karst regulations can be constructed.

Perhaps the most direct way to answer these questions would be to simply ask the people who spend their careers designing and working with these exact

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regulations—land use planners and professionals. Their years of experience would certainly yield valuable insight into the inner workings of karst-related land use policy. In late 2006, a sampling of these insights was collected via an online survey of land use professionals working in karstic areas of the United States. Planners from Florida, Kentucky, Missouri, New Jersey, Pennsylvania and Tennessee participated in the survey, with the heaviest responses coming from Florida and Pennsylvania. The intent was to collect a broad cross section of data on planners' awareness and opinions on the challenges of protecting human systems and karst systems from each other.

The survey's 36 questions were mostly multiple choice and touched on six broad issues in karst land use regulation:

- How widespread is karst knowledge in the planning community?
- How widespread was the practice of regulating development in karst areas?
- What kinds of karst regulations were most common? What mechanisms were included in these regulations? Are there differences from region to region?
- What motivated the implementation of these regulations? What problems were they intended to address?
- Which groups had the most influence on the process of regulatory development? Which groups had the least?
- What is the actual effect of these regulations? Do they work? What do they actually accomplish?

In the next section of this chapter, we'll take a broader look at the general trends in the survey results, followed by a more detailed examination.

Survey Results: How Planners Think About Karst

As analytical techniques go, simply scanning the survey results and counting the responses may seem pretty superficial. However, it can provide some useful and interesting insights. Specifically, we can learn what planners do and do not generally know about karst, as well as their conscious opinions on karst-related topics. But as we will see later, some of these front-of-mind opinions are actually contradicted by answers to other survey questions. First, however, an overview.

Location of Respondents and Familiarity with Karst

The survey began with a series of questions designed to gauge who had responded to the survey and whether their insights were likely to be useful in developing the framework. Of the survey's respondents 65% were from either Florida or Pennsylvania, with the balance split between Kentucky, Missouri, New Jersey, and Tennessee, and 82% work in the local government.

Eighty-nine percent of the survey participants claimed some familiarity with karst. This is not surprising since some effort was made to target respondents from karstic areas; 56% of the respondents said they are aware of some form of karst regulation on the books in their municipalities. The question was phrased broadly, which means that these ordinances almost certainly include a wide variety of regulatory techniques and may differ significantly in terms of regulatory scope and strength.

Those who indicated that they were not aware of any karst-related land use regulations in their communities were asked why these regulations were not in use. The absence of karst geology within municipal boundaries was cited by 11% of respondents, while approximately 17% cited either philosophical opposition to regulation or pressure from developers as the primary reasons for the lack of regulation. In the free response segment of this question, several people placed the blame on a lack of information on or understanding of karst; others answered that they did not feel karst issues were significant enough to merit such a high level of attention:

- "The lack of sufficient information regarding active sinkhole areas is the biggest reason that no specific regulations have been developed. Although this area is considered karst topography, it has not presented a major problem with development."
- "Not an issue that has been raised to the level of needing to be addressed."
- "There has been no driving force to implement such regulations."
- "Lack of knowledge on the subject and no directive from policy makers to make it an item of discussion."
- "Our SALDO (subdivision and land development ordinance) is very old and has not been updated for some time. This has not been a significant issue for our development."
- "Allocation of time and resources to other pressing issues."

Characteristics of the Local Karst and the Nature of Karst-Related Issues

It is clear that many of the cities, towns and counties where survey participants work are prime candidates for karst-related land use regulation. Seventy-five percent of respondents indicated that karst underlies more than 30% of their municipality's land area, with 32% describing the karst system as extensive ("extensive" is defined here as existing beneath at least 51% of their municipality's territory). Different types of karst landforms seem to be distributed more or less evenly throughout these communities. All respondents working in municipalities underlain by karst say that sinkholes are present in their municipalities; 94% have springs in their municipalities, while both caves and sinking streams are present in 74%. This similarity suggests that any differences in which regulatory techniques are chosen will be driven by factors other than the nature of karst landforms in the municipality.

Forty-eight percent of respondents point to groundwater contamination as the most serious karst-related problem in their municipality, while 63% say that cave protection is the least important karst-related problem. These results are more or less mirrored in another question that asked respondents to rate the severity of various karst-related problems as "very serious," "somewhat serious" or "not serious." Here again, groundwater contamination was seen to be the most serious karst-related issue and cave protection the least.

The Regulations Themselves: Components, Restrictiveness and Goals

A majority of respondents indicate that karst regulations in their jurisdictions have some teeth. Fully 54% see the karst-related land use regulations in their municipalities as either somewhat or very restrictive. Survey participants were given no definition of "restrictive"; this was intentional, as one goal of the survey was to determine what the survey subjects themselves consider the word to mean. We will return to this issue later in the chapter.

Groundwater protection, general environmental protection, and a desire to limit structural damage from sinkholes were the most common reasons for implementing regulations in the first place; far less frequently cited reasons included cave protection and avoiding litigation (only seven percent cited cave protection as a motivation for passing karst regulations). Stormwater drainage regulations are by far the most common regulatory technique employed for these purposes (cited by 90% of respondents), followed by mandatory setbacks (58%), dumping and waste disposal rules (55%), and additional steps in the permitting process (52%). Sixty-seven percent say that karst-related land use regulations were implemented in their municipalities as a reactive measure to address pre-existing problems, rather than as a preventative measure. Participants who said their regulations were reactive cited contamination of groundwater resources and damage to property as the primary drivers in pursuing regulation-based solutions:

- "Sinkholes have caused extensive damage to buildings, highways, utilities and public facilities. Sinkholes have even led to death in connection with natural gas lines."
- "County growth made the regulations necessary for ground water protection, flooding, property damage, and general environmental conservation."
- "A backyard collapsed due to development over a karst system. At the time the house was worth 62 thousand and it cost about 175 thousand to fix the problem."
- "Flooding of new lakeside homes where developer illegally diverted stormwaters into an injection well/sinkhole without a TDEC Class V injection well permit. Sinkhole backed up and also flooded downstream before waters entered lake."
- "Mostly preventative, except for issue of groundwater/aquifer impact, which had been ongoing."
- "No storm sewer system; sinkholes used for storm water disposal."

- "Excessive nitrates in groundwater and stormwater affecting surface water quality."
- "Often communities try to pass a carbonate ordinance when they are faced with a potential development coming to town."
- "Sinkhole activity had contributed to destruction of roadway surfaces, detention ponds and drainage courses. There was additional impact on private wells and a public water supply."

The Implementation Process: Stakeholders, Time, and Other Factors

It is difficult to fully understand the regulatory process without knowing who drives it. According to the survey results, 39% of the time, proposals for regulating land use in karst terrains came from a branch of local government; 21% of the time, it came from state or federal government instead. In most cases (62%), these regulations were ultimately approved and implemented by a commission or other elected body, with a single elected official being responsible for implementation 21% of the time.

When asked about the length of time it took for karst-related land use regulations to be implemented in their jurisdictions, nearly 40% say it happened within two years of the initial proposal (33% either don't know or don't remember how long it took, which was the second most popular response). This suggests that certain policy analysis tools that focus on the long term, like Sabatier's Advocacy Coalition Framework (Sabatier and Jenkins-Smith 1988; Sabatier 1991), may not be completely appropriate for use in analyzing the implementation process of karst-related land use regulations.

In many cases, there was a varied mix of people and entities that contributed some input into the process of developing these regulations; of the options provided, the two that were selected least frequently are the building and construction industry (18%) and the federal government (15%). Local government departments were generally recognized as having the most influence on the process (52%); the federal government was recognized as the least influential (52%).

Non-elected professionals were influential: Forty-seven percent of participants said they had a strong influence on the development of the regulations that were ultimately implemented. Some representative comments from this group of respondents include:

- "Geologist, soil scientist, hydro geologist, biologist, and others all have had a significant role in conducting solid science to be used in development of the rule;"
- "Regulations reflected credible engineering and geologic knowledge and experience;"
- "Provision of the science base for understanding groundwater, the aquifers in the state, the rate of recharge, etc., affected decisions prioritizing areas that are karst sensitive and in developing the land use regulations to protect them."

Local residents, on the other hand, did not seem to have much influence on the regulations: 33% of respondents described local residents' influence as "slight," while 18% called it nonexistent. In cases where local residents had a greater influence on the regulation development process, no real pattern emerges; one respondent suggests that citizen participation is tied to the level of danger posed to residences by karst, but this theme is not repeated in other responses:

- "Where houses have been subject to flooding, there was major clamoring to solve problems. . .buy-outs and identification of flood limits around sinkholes."
- "Local residents participated in the process; were generally supportive."
- "Public input was a continuing part of the process of developing land use regulations, through the comprehensive planning review process."
- "The reporting of the various incidents provided sufficient documentation to warrant investigation of appropriate regulations and safeguards."
- "Clearly, the public is concerned about the occurrence of sinkholes as it is a regular 'phenomenon' due to subsurface conditions, location between three bodies of water, and the early, dense urban development of the City pre-federal, state or local land use regulation. City Planning, Zoning and Engineering personnel took the lead develop and enforce regulations in the interest of the public health, safety and welfare."

Survey participants say that generally, these regulations were not affected by other land use regulations already in place. Thirty-nine percent of respondents claimed that pre-existing land use regulations and ordinances had no influence on the development of the karst-related regulations; 24% said there was some influence but described it as slight. Several respondents offered more information in the free response section; the ones listed here are from those who felt that existing land use regulations had either no impact or only a slight influence on karst regulatory development in their jurisdictions:

- "City had previously passed Creek regulations governing increased setbacks."
- "Karst regulations represented a new field of regulation."
- "[Regulations were] part of comprehensive plan."
- "State already had regulations about setback of septic systems from karst areas (sinkholes etc.) which were incorporated in development reviews."
- "Knowledge of related state regulations was used in pressuring the local elected officials to push for adopting similar regulation."

Expected Outcomes and Actual Outcomes of Karst Regulation

Some of the more interesting findings of this survey are the differences between what respondents say they would expect to come from implementing additional regulation on development in karst terrains and what actually happened. For example, 34% of respondents indicated they would expect the implementation of karst regulations to lead to an increase in housing costs, but only 11% actually observed this reaction. Likewise, 18% say they would anticipate the number of new development projects in a town that regulates development on karst to decline. However, only 7% claim to have seen new projects locate elsewhere as a result of the presence of karst-related land use regulations. Similarly 14% said they would expect population density to decline; again, a much smaller percentage (two percent) actually saw this happen as a result of implementing karst regulations. Perhaps most surprising is that totally 75% of respondents said they would expect to see an improvement in groundwater quality as a result—but only 19% actually did.

The expectations of survey participants of the outcomes of adding additional regulatory requirements to development in karst terrains varied widely. Qualitatively speaking, expectations expressed here tended to be distinctly positive or distinctly negative; very few responses incorporated both viewpoints. The list below is a representative sample:

- "Effects on development could vary; could reduce development & increase housing costs, but karst features could also become a valued amenity to property."
- "Lower property insurance rates; a decline in structures collapsing or subsiding into the karst features."
- "A decline in build-out population and structural density due to better treatment of stormwater and the need for more space for surface water treatment. 2) More groundwater recharge areas. 3) Open space dedications in very karst areas, spring protection zones."
- "Improved public safety, preservation of land values, landscape appropriate development, increased environmental quality."
- "None. Karst regulations carry the same weight as other design criteria found in local land use ordinances, i.e., stormwater management, traffic, improvements layout, floodplains, watercourses, etc."
- "It would be very difficult to isolate areas that this type of regulation would apply. Developers in Florida are required to do hydrogeological tests to determine subsurface conditions. Even with these tests, sinkhole activity in Florida is hard to predict."
- "Increase in development related lawsuits. Also, increase in number of variances requested (to develop where karst exists)."
- "Increase in development costs. Level or declining tax base."

When subjects were asked about the outcomes of implementing karst regulations that they actually observed, there is a sharp difference in tone and content from these expectations. Respondents did not observe regulations to have a significant impact on development costs, and some even felt the regulations improved the overall quality of development decisions:

- "A slight increase in cost of permitting for a small number of developments."
- "Housing costs have increased in the last 15 or so years since the initial regulations were put in place, but I don't think there is any correlation between these costs and the regulations."

- "Better development decisions can be made due to the requirement that karst features be identified on subdivision plats."
- "More environmentally appropriate development."

Finally, 70% of respondents say that decisions on whether or not to adopt karst regulations were not influenced by the presence or absence of karst regulations in neighboring towns. This sort of strategic behavior and its implications will be examined in more detail later in this book.

Appropriateness and Effectiveness of Regulating Development on Karst

Survey participants were overwhelmingly friendly to the concept of regulating development on karst, with 97% saying it is an appropriate thing for municipalities to do. Whereas 68% said the karst-related regulations in force in their own jurisdictions are effective; 18% say they are not, with the balance expressing no opinion. Even so, 70% of respondents said they feel there is room for improvement in their municipality's karst regulation strategy. Recurring themes on this topic included tightening restrictions on development in karst areas, improving information flow (both between government and the public and between different branches of government), and enforcement and follow-through by regulating agencies:

- "I'm not sure that building sites are always well selected in relation to karst . . . implication: potential review with building permit, especially on pre-existing subdivisions (prior to setback provisions that are currently called for with newer subdivisions)."
- "Get more municipalities to adopt [karst land use regulations]."
- "Provide more restrictions and not allowing the filling in of sinkholes unless approved via a public hearing."
- "We could require further setback from 'inactive' karst features; we could require 'high performance' septic tanks or central sewer systems as a minimal requirement for low density residential development, to remove nitrates and reduce their impact to groundwater/aquifer."
- "We need to add buffering or preserves around known sinks and other karst areas. Right now we rely heavily on the Flood Damage Prevention Resolution to protect all waters of the state, the Illicit Discharge Detection and Eliminary Resolution to regulate illegal dumping, and more specifically holding up all construction plan approval until the State's geologist can approve any new subdivisions where sinkholes and caves have been identified, thus requiring injection well permits if stormwater diverted to sink or at least protection around the cave/sink during construction. We definitely can stand to improve our regs."
- "Better mapping of karst areas and stronger follow-up by the regulating agencies."

- "Could expand consideration to all development situations, particularly commercial site plans."
- "Mapping karst area and grading their vulnerability to sinkhole formation and ground water contamination and making these maps available to the public."
- "Educating the general public to the necessity of it. More can always be done."
- "Larger karst feature setbacks, and larger setbacks in general for environmentally sensitive areas, i.e., riverine corridors."
- "Better coordination between sectors of government and other government entities."

A More Detailed Analysis of the Results

Certainly a surface-level examination of these results has plenty to offer us, in and of itself. However, by cross-referencing responses, we can gain much more insight into what they really mean—and we even turn up a couple of interesting contradictions in the process.

The Meaning of "Restrictive"

As discussed earlier, a slim (54%) majority of survey participants described the karst restrictions in place in their communities as either "very restrictive" or "somewhat restrictive." However, the value of knowing that is limited unless we can define these terms more precisely, at least in terms of what the survey participants think they mean in this context. For example, are there specific regulatory techniques that are associated with more restrictive regulations? If so, which ones?

Cross-referencing responses between relevant survey questions, begins to draw out the relationship between perceived regulatory restrictiveness and the use of specific regulatory tools within the sample. Table 3.1 shows that, in general, most regulatory tools increase penetration rates as perceived regulatory restrictiveness increases. In particular, mandatory setbacks and extra administrative steps in the permitting and building process are significantly more common in jurisdictions with higher perceptions of regulatory restrictiveness. This suggests that the respondents' views of what constitutes "restrictiveness" is not completely subjective and does in fact seem to be tied to the implementation of certain regulatory techniques. One exception to this pattern is stormwater drainage regulations. Stormwater regulations are almost universally applied, regardless of the overall restrictiveness of the karst regulations in place. Responses from follow-up interviews suggest that this may be related to the relatively high visibility of unaddressed runoff-related problems (since politicians are more likely to respond to issues that are more visible and immediate), as well as the comparative ease of getting developers to comply with these regulations.

Table 3.1 Perceived restrictiveness of karst regulations

	Not at all restrictive	Not very restrictive	Somewhat restrictive	Very restrictive
Total observations in each category	2	12	15	4
Techniques used				
Mandatory setbacks	0	5 (41.66%)	10 (66.66%)	4 (100%)
Single extra step	0	3 (25%)	9 (60%)	4 (100%)
Multiple extra steps	0	2 (16.66%)	4 (26.66%)	2 (50%)
Stormwater drainage	2 (100%)	10 (83.33%)	14 (93.33%)	4 (100%)
Dumping and waste disposal	1 (50%)	5 (41.66%)	9 (60%)	3 (75%)
Fertilizer and chemical application	0	0	4 (26.66%)	2 (50%)
Other options	*(the following regulatory tools were mentioned in the free response segment of this question)*			
Zoning overlay	0	0	1 (6.66%)	0
Designation of non-buildable areas	0	1 (8.33%)	0	1 (25%)
Sinkhole area excluded from minimum lot size requirements	0	1 (8.33%)	0	0

Numbers in parentheses reflect the percentages of communities in each restrictiveness category that employ a given regulatory technique

Goals, Effectiveness and the Potential for Improvement

By identifying the specific goals of regulating development on karst terrains, we can examine questions relating to the comparative effectiveness of these regulations. For example, are these regulations more effective in achieving some goals than others? Are certain regulatory techniques more effective than others? Are some of the most frequently cited goals of karst land use regulation perhaps too large to resolve via the regulatory tools available to local governments?

Table 3.2 lists five common goals of karst land use regulation, alongside the number of times each was named as a regulatory goal by survey participants. This is

Table 3.2 Relationship between regulatory goals and perceived regulatory effectiveness

Regulatory goals	Number of respondents citing each goal	Effective?	
		Yes	No
Environmental protection	22	14	4
Groundwater protection	30	19	6
Cave protection	7	4	2
Limit structural damage from sinkholes	28	21	5
Limit governmental liability in lawsuits	11	9	2

cross-referenced with a question about the perceived effectiveness of karst land use regulations in each respondent's community. For example, of the 30 subjects who said that groundwater protection was one of the goals of their jurisdictions' karst regulations, 19 felt those regulations were effective, while six felt they were not.

(It should be pointed out that this does not necessarily mean that the survey participants felt the regulations were effective in addressing that concern specifically; instead, "effectiveness" is taken to mean the *overall* effectiveness of the karst regulations.)

These responses do not offer a clear relationship between the nature of regulatory objectives and the perceived effectiveness of the regulations. Part of the reason for this is the general consensus among survey participants that these regulations are, in fact, effective: over 67% of respondents feel that way, with the remainder almost evenly split between dissenters (17.65%) and those with no opinion (14.71%). This high level of satisfaction poses a problem in comparing the effectiveness of various regulatory techniques, since there are simply not enough "ineffective" votes to be confident in the results, statistically speaking. For this reason, examinations of the perceptions of regulatory effectiveness throughout the rest of this chapter will be limited.

That said, let us now briefly look at the effectiveness responses and how they correlate with respondents' opinions on potential improvements in their karst regulations. Table 3.3 displays the relationship between perceived regulatory effectiveness and perception of potential for improvement in local regulations. It should not surprise anyone that survey participants who think their jurisdictions' regulations are ineffective would say that these regulations could be improved. It may, however, be somewhat surprising to see that respondents who consider their jurisdictions' karst regulations to be effective *also* feel that there is room for improvement in those regulations, by a nearly three-to-one margin.

At first glance, this appears to be a tricky contradiction to reconcile: if a regulation or ordinance is effective, then why would it require improvement? Certainly the word "effective" in this context implies that the regulation or ordinance has achieved its goal, either in full or in part. And perhaps this is our explanation: respondents may be interpreting the word "effective" as meaning "at least partially successful in achieving its goals." If that is the case, this may reflect the political difficulties involved in implementing laws and regulations that restrict development and growth based solely on the presence of an obscure geologic phenomenon. So something is better than nothing, but more would have been even better.

Table 3.3 Relationship between perceived regulatory effectiveness and perception of potential improvement in local regulations

Are local karst land use regulations effective?	Is there room for improvement in local karst land use regulation?	
	Yes	No
Yes	13	5
No	3	1

How the Extent of the Local Karst Affects Choice of Regulatory Technique

Certainly, the amount of karst found beneath a municipality should influence the final form of any karst regulations implemented there. For example, more comprehensive regulatory approaches may not be appropriate for locations where the extent of karst is limited; likewise, areas with significant karst should probably consider passing more than a simple stormwater runoff management ordinance. In practice, municipalities generally have to make that determination—how much regulation is enough—on their own. By consulting Table 3.4, which describes the relationship between karst system size and regulatory techniques employed in the survey sample, we can identify the regulatory components that are more commonly used in areas with extensive karst, as well as those used in locations with limited karst geology.

It is clear from Table 3.4 that stormwater drainage rules are the most preferred regulatory technique. These rules are widely applied, regardless of the amount of karst present. Mandatory setbacks become a more preferred regulatory technique as the amount of karst present increases. In fact, setbacks, waste disposal and dumping, and chemical application are used most frequently by jurisdictions with the most extensive karst systems, while extra steps in the permitting and building process seem to be preferred in communities with moderate karst (in other words, municipalities in which between 31 and 50% of the land is underlain by karst).

Only one survey participant said that a zoning overlay is in use in his or her community, despite having only a minimal karst presence there. A zoning overlay would,

Table 3.4 Relationship between the extent of local karst systems and the regulatory techniques used

	Extent of karst			
	< 10%	10%–30%	31%–50%	> 50%
Total observations in each category	2	6	15	11
Regulatory techniques used				
Mandatory setbacks	0	3 (50%)	9 (60%)	7 (63.63%)
Single extra step	1 (50%)	3 (50%)	9 (60%)	5 (45.45%)
Multiple extra steps	0	1 (16.66%)	5 (33%)	3 (27.27%)
Stormwater drainage	2 (100%)	6 (100%)	12 (80%)	10 (90.9%)
Dumping and waste disposal	0	3 (50%)	6 (40%)	9 (81.81%)
Fertilizer and chemical application	0	0	1 (6.66%)	4 (36.36%)
Other options	*(the following regulatory tools were mentioned in the free response segment of this question)*			
Zoning overlay	1	0	0	0
Designation of non-buildable areas	0	0	2	0
Sinkhole area excluded from minimum lot size requirements	0	0	1	0

Numbers in parentheses reflect the percentages of communities in each restrictiveness category that employ a given regulatory technique on the surface, seem to be one of the more restrictive approaches to development in karst terrains; the fact that it is employed by a jurisdiction with such low levels of karst is interesting and may indicate that the specific requirements of that particular zoning overlay district are modest.

It would also be interesting to compare the subjects' perception of regulatory restrictiveness to the extent of karst present in their jurisdictions. We would expect the results, shown in Table 3.5, to track closely with the results from the previous comparison. Very generally speaking, one could make the argument that the perceived restrictiveness of a jurisdiction's regulations is loosely related to the extent of the local karst. However, the low numbers of respondents makes it difficult to definitively conclude anything.

Table 3.5 Relationship between the extent of the local karst system and the perceived restrictiveness of local karst regulations

	Local extent of karst			
	< 10%	10%–30%	31%–50%	> 50%
Total observations in each category	2	6	15	11
Perceived restrictiveness of local karst regulations				
Not at all restrictive	1	1	0	0
Not very restrictive	0	2	5	5
Somewhat restrictive	1	3	7	4
Very restrictive	0	0	2	2

Preventative or Reactive Implementation and Regulatory Restrictiveness

When asked if karst regulations were enacted as a preventative measure or in response to a specific, ongoing issue, most said that regulations had been implemented reactively rather than preventatively. This is worth noting because of the possibility that the circumstances surrounding the implementation of regulations may have affected the form the regulations took: if, for example, a town's karst regulations were hurriedly passed in response to a serious, recently discovered problem with groundwater quality, those regulations may be too restrictive or otherwise inappropriate as a method of addressing the groundwater problem over the long term. There may be differences in the restrictiveness and effectiveness of karst regulations that were enacted as a preventative measure and those that were implemented reactively.

Table 3.6 suggests that regulations enacted in response to a specific problem that is already occurring tend to be more restrictive than those implemented as a preventative measure. This does lend some weight to the idea that reactively passed regulations may be a bit too restrictive; on the other hand, it could also mean that more restrictive regulations are required to repair an established, entrenched problem than

Table 3.6 Relationship between the nature of local regulations and their perceived restrictiveness

Perceived restrictiveness	Were local karst regulations implemented to be preventative or reactive?	
	Preventative	Reactive
Not at all restrictive	1	1
Not very restrictive	3	7
Somewhat restrictive	6	9
Very restrictive	0	4

Table 3.7 Relationship between the nature of local regulations and their perceived effectiveness

Perceived effectiveness	Were local karst regulations implemented to be preventative or reactive?	
	Preventative	Reactive
Effective	6	17
Not effective	3	2

to head off a potential future issue. Even more striking than that is the effective/not effective split shown in Table 3.7: respondents in jurisdictions where karst regulations were implemented in a reactive manner are far more likely to consider those regulations to be effective than are respondents from communities that enacted preventative karst regulations instead. At first glance, this may appear to bolster the idea that reactive regulations are more restrictive because they have to be. However, it may simply be another illustration of the notion that more restrictive regulation is by definition more effective. Another possible explanation is that cases where preventative measures were taken, the karst-related problems they were intended to prevent were by that point inevitable; the fact that they eventually occurred even after regulations were put in place could then be seen as "proof" that the preventative regulations were inadequate.

Initiators vs. Restrictiveness

Different actors may begin the process of implementing karst-related regulations for different reasons and may have distinctly different goals. Those differences may make themselves apparent in the specific forms taken by the resulting regulations. Table 3.8 shows the relationship between the initiators of the regulatory process and the perceived restrictiveness of the regulations that emerged from the process. Branches of local government were by far the most frequent initiators of regulation; most of these regulations came down squarely in the middle measures of regulatory restrictiveness. Certainly, one thing this table does show us is that who began the process of developing karst land use regulations has little, if anything, to do with the overall level of restrictiveness of those regulations.

We can probe this question a bit further by comparing initiators to the individual components used in these regulations. The results are provided in Table 3.9.

Table 3.8 Relationship between initiators of local karst regulations and perceived restrictiveness

Initiators of local karst regulations	Perceived restrictiveness			
	Not at all restrictive	Not very restrictive	Somewhat restrictive	Very restrictive
Branch of local government	2	6	5	1
Branch of state or fed government	1	4	2	0
County commission or equivalent	1	2	2	0
Environmental or science groups	0	2	0	0
Other	0	1	0	1

From these results, it is difficult to generalize about the influences of the different regulatory initiators in the final form of the regulations themselves. It does seem clear that regulations initiated by state and federal levels of government are less likely to incorporate mandatory setbacks than other techniques, like stormwater runoff and drainage management or additional steps in the permitting and building process.

Table 3.9 Relationship between regulatory techniques used and identity of regulatory initiators

	Regulatory initiators				
	Branch or department of local government	Branch of state or federal government	County or city commission	Environmental or science groups	Other
Total observations in each category	*15*	*7*	*6*	*2*	*2*
Regulatory techniques used					
Mandatory setbacks	10	2	4	1	1
Single extra step	7	6	2	1	1
Multiple extra steps	4	2	2	1	0
Stormwater drainage	13	7	5	2	2
Dumping and waste disposal	8	4	2	1	1
Fertilizer and chemical application	2	3	0	1	0
Other	5	0	1	0	0

The Influence of Non-elected Professionals vs. Regulatory Restrictiveness

It is unrealistic to expect most elected officials to have detailed knowledge and understanding of karst and the challenges it poses to human systems above it. Therefore, input from people with subject-specific expertise could easily become a critical factor both in the development of karst regulations and in the form they ultimately take. In particular, it would be very easy for elected officials to either overestimate or underestimate the severity of karst-related problems without input from non-elected professionals like engineers, geologists, or hydrologists, among others. Table 3.10 displays a rough sketch of the impact of professional input on karst-related land use regulations. There seems to be no relationship at all between the amount of influence exerted by non-elected professionals and the restrictiveness of the resulting regulation. At all levels of professional influence, the distribution of regulatory restrictiveness is once again centered around "not very restrictive." It is interesting to note that there is no trend toward excessive regulation as the influence of non-elected professionals increases.

As when examining the role of regulatory initiators in the previous section, this question can be examined in more detail by including a comparison between levels of non-elected professional influence with the appearance of specific regulatory tools in the karst land use ordinances; this comparison is shown in Table 3.11. As

Table 3.10 Relationship between levels of influence of non-elected professionals and the perceived restrictiveness of the resulting regulations

Level of influence from non-elected professionals	Perceived restrictiveness of karst regulations			
	Not at all restrictive	Not very restrictive	Somewhat restrictive	Very restrictive
None	0	0	0	0
Slight	0	3	1	0
Moderate	1	5	1	0
Strong	3	8	3	1

Table 3.11 Relationship between regulatory techniques employed and the level of influence over the regulatory process displayed by non-elected professionals

	Level of influence from non-elected professionals			
	None	Slight	Moderate	Strong
Total observations in each category	*0*	*4*	*7*	*16*
Regulatory techniques used				
Mandatory setbacks	0	4	4	8
Single extra step	0	1	4	11
Multiple extra steps	0	1	0	8
Stormwater drainage	0	4	7	15
Dumping and waste disposal	0	0	6	9
Fertilizer and chemical application	0	0	2	4
Other	0	1	1 (overlay)	3

the influence of non-elected professionals increases, so too does the likelihood that extra steps are included in the permitting and development process for projects in karst areas; likewise for dumping and waste disposal and fertilizer and chemical application.

Expected Outcomes vs. Propensity to Regulate

As we have seen elsewhere in this book, regulating land use is often a politically charged endeavor, with many strongly held opinions on both sides of the issue. One might wonder how these opinions affect the process of implementing karst land use ordinances and regulations: is it possible that towns in which land use professionals and policymakers have negative expectations regarding the outcomes of karst land use regulations are less likely to implement such regulations? By displaying the differences in the expected outcomes of karst land use regulation among land use professionals in towns that regulate development on karst and towns that don't, Table 3.12 shows that this is, in fact, the case. In this table, outcomes that could best be described as "positive" are connoted by a (+) symbol; negative outcomes are connoted by a (−) symbol (the "decline in density" option could be defensibly described as either positive or negative and is thus not assigned a qualitative descriptor here). Note that the two negative responses—increasing housing costs and a decline in new development projects—were selected as likely outcomes significantly more often by respondents from jurisdictions where karst regulations are not in place. Likewise, two of the three positive responses (a decline in litigation filed against the city and improved groundwater quality) were much more likely to be identified as expected outcomes by respondents from jurisdictions in which karst land use regulations had been enacted.

Survey participants were given the opportunity to describe the nature of outcomes they anticipated that might not be explicitly listed in the survey. Expected outcomes

Table 3.12 Differences in expected outcomes of karst regulation between towns that do regulate and towns that do not

	Regulating		Not regulating	
Total observations in each category	*32*		*21*	
Expected outcome				
	Total	Pct (%)	Total	Pct (%)
Increasing residential land values (+)	5	15.6	4	19
Decline in litigation (+)	7	21.9	0	0
Improved groundwater quality (+)	25	78.12	8	38.1
Decline in density	3	9.4	4	19
Increasing housing costs (−)	4 (2 overlap)	12.5	11 (3 overlap)	52.38
Decline in new development projects (−)	2	6.25	7	33.3
Other outcome	11	34.37	3	14.28

A (+) represents a positive outcome; a (−) represents a negative outcome. No sign indicates a neutral outcome, or one that could widely be perceived as either positive or negative.

identified by respondents from communities in which karst-related regulations were present included:

- Less structural damage;
- more groundwater recharge space;
- more open space dedications;
- improved public safety;
- landscape appropriate development;
- lower property insurance rates;
- better education and communication between developers, state and county;
- reduced incidents of flooding and subsidence;
- increased public awareness; and
- nothing at all.

Respondents from communities where development on karst had no additional restrictions, on the other hand, provided the following list of expected outcomes:

- Increase in development costs;
- level or declining tax base;
- increase in development-related lawsuits; and
- increase in number of variances requested.

In terms of anticipating positive or negative outcomes, the qualitative difference in expectations between respondents from regulating areas and those from non-regulating areas is striking. While respondents from both groups selected both positive and negative outcomes from the list of supplied answers, there was no crossover at all in the free response answers: of the ten free response answers provided by respondents from regulating communities, only one ("nothing at all") can be construed as even a neutral response, with the remaining nine being positive expectations. Similarly, three of the four free response answers from respondents living in non-regulating areas are negative expectations, while the fourth ("increase in number of variances requested") can be seen as a neutral response.

There are two possible explanations for these results that spring immediately to mind. First, they may be representative of a divergence of attitudes toward regulation in general, which is already reflected in the difference in practice of karst regulation. Second, with regard to respondents with positive expectations of the results of karst regulation, these results could be a matter of respondents projecting their current understanding of and attitudes toward karst regulation backwards.

By examining responses from individuals working in regulating municipalities only, we can now compare respondents' expected outcomes with the results they actually observed. Table 3.13 makes clear that in most cases, neither the positive nor the negative expected outcomes of karst-related land use regulation came to pass once the regulations were implemented. An improvement in groundwater quality was observed in five communities where karst-related regulation was implemented; all five of these respondents indicated that they would expect to see such an improvement ("overlap"). In no other case was the overlap

Table 3.13 Differences between expected outcomes and observed outcomes of regulating karst (municipalities that regulate only)

Potential outcomes	Expected	Observed	Overlap
Higher housing costs	4	1	1
Lost development opportunities	2	1	1
Improved groundwater quality	25	5	5
Decrease in subsidence-related damage*	5	8	1
Decrease in density	3	1	1

* *expectations were expressed in the free response section of this question*

quantity more than one. In only one instance did more respondents observe an outcome (a decrease in subsidence-related damage) than indicated they would expect such an outcome; even so, only one respondent overlapped between expectation and observation. Most of the negative expectations of respondents from non-regulating communities also did not materialize in towns that chose to regulate.

Eight respondents indicated they saw no impacts of the karst land use regulations implemented in their jurisdictions; four others described observed outcomes not mentioned in the survey:

- A small increase in permitting costs for some developments;
- Better development decisions due to increased amount of information;
- More environmentally appropriate development; and
- Stronger ties between state and local development regulations and procedures.

A fifth respondent said that he or she had observed rising housing costs over the last fifteen years, but added that there is probably no direct connection to the karst regulations in place there.

One interesting thing about the data shown in Table 3.13 is that they are contradicted to some extent by the data in Table 3.2. In that table, we see that nearly two-thirds of respondents who cited groundwater protection as a motivating force for implementing karst land use regulation felt the regulation had been effective in achieving that goal. Yet in Table 3.13, only 20% of respondents who expected to see an improvement in groundwater quality could say that they had observed such an improvement. Why the discrepancy? The most obvious explanation is that these respondents simply assumed the regulations had been effective, despite not having observed any actual improvement.

The responses displayed in Tables 3.12 and 3.13 have particularly interesting implications. First, there is a strong suggestion that attitudes of land use professionals could be a major factor in determining whether or not karst regulations are passed at all. Second, the expected results of karst land use regulation—both positive and negative—often do not come to pass. One exception to this was a decrease in subsidence-related damage; more respondents observed this result than anticipated it. Both of these conclusions could in turn have significant implications in the process of implementing karst land use regulations.

Summary: What Planners Can Tell Us About Karst Land Use Regulation

The planners who participated in this survey revealed—both directly and indirectly—a great deal about karst regulation and how it works. While not all of this information will be useful in constructing the framework, some of the more noteworthy conclusions include:

- Stormwater drainage and runoff regulations are the most popular method of regulating development on karst terrains;
- Employing mandatory setbacks as a regulatory tool is more common in municipalities with more extensive karst formations;
- Attitudes held by planners on the likely outcomes and impacts of karst land use regulation seem to have an influence on whether or not such regulations are imposed;
- The expected results of karst regulation, particularly "secondary effects," like changes in population density or growth rates, often do not come to pass;
- Seeking input from non-elected professionals (for example, geologists, engineers, hydrologists) does not lead to inherently more restrictive regulations;
- No clear relationship can be identified between the restrictiveness of the regulations and the identity of the initiator of the regulation implementation process;
- "Reactive" regulations tend to be more restrictive than preventative regulations;
- Often, respondents will say that karst regulations are effective methods of achieving a particular goal, even if they haven't actually witnessed it;
- Strategic behavior does not seem to be an issue in the process of deciding whether or not to implement karst land use regulations.

It's important to remember that, because planners are human and often have personal connections to these ordinances, we cannot simply accept their assertions at face value. Over the next two chapters, we will see the opinions and ideas shared by the survey sample examined in real-world situations. Both chapters present case studies designed to explore how human populations, karst systems and karst land use regulations interacted, in different environments and under varying conditions. And while many of the answers provided in this survey are confirmed by these case studies, there are some divergent results as well.

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Chapter 4
The Practical Impacts of Karst Regulations on the Communities that Implement Them – a Pair of Case Studies

Abstract Urbanization and its related activities in karst landscapes often generate significant threats to karst aquifers. Industrial activities, street runoff, and waste disposal have the potential to deposit contaminants directly into the aquifer, particularly after a good rain. This chapter includes two case studies that examine how karst land use regulations work in a real-world context. The first looks at cities in Kentucky and Missouri in an effort to identify the ways, if any, in which mandatory setback ordinances affect density in the areas where they are applied. The second uses data from municipalities in Pennsylvania to explore what, if any, economic impact the act of implementing karst-aware land use regulations has within the municipalities that choose to do that. While the Pennsylvania case study finds no evidence of any economic impact brought about by implementing karst-related land use ordinances, the first case study suggests that the influence of setbacks on densities is ambiguous.

Keywords Urbanization · Density · Economic impact · Karst ordinances and regulations · Pennsylvania · Kentucky · Missouri · Setbacks

Karst land use regulations place restrictions on how people are able to use the land they live on. Sometimes these restrictions are negligible. However, in some circumstances they can impose significant inconveniences for anyone who lives near a karst feature, or above a heavily karstified limestone aquifer. In these cases, there is a trade-off: more diligent karst protection in exchange for accepting limits on what you may be permitted to do with your piece of property. That exchange is at the heart of any proposal to enact karst land use regulations.

But in order to make an informed decision about this trade-off, local residents need some idea of the practical effects of accepting these limits. How will the regulations affect the way in which they live their day-to-day lives? How will they impact the local economy? How will densities change? These are very real questions that should be answered before a sinkhole ordinance is approved and they form the basis for the case studies conducted in this chapter.

This chapter looks at two examples of what happens to cities and towns when karst land use regulations enter the equation. It asks what observable, measureable impacts karst land use regulations have on the communities that use them, and uses

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demographic, economic and geologic data to begin to flesh out an answer. The discussion will be limited to two general types of impact—impacts on population and housing densities and economic impacts, particularly lost opportunities for growth and development.

The first case study examines four cities in Missouri and Kentucky and focuses on ways in which karst regulations change the physical form of cities and towns—specifically housing densities. The second uses data collected from cities and townships across south-central Pennsylvania and explores questions of economics—specifically, does a municipality that adopts karst land use restrictions put itself at a competitive disadvantage with respect to its neighbors that do not use such techniques? Certainly planners, policymakers and private citizens alike have an interest in answering these questions as carefully as possible before approving any karst-sensitive land use ordinances.

Case Study One: The Impact of Sinkhole Setbacks in Kentucky and Missouri

As we have seen in the preceding chapters, karst land use regulation is common throughout the United States. While these regulations and ordinances are usually adapted to meet local conditions, some regulatory techniques are employed in very different environments. This first case study examines one of these common techniques—the setback—and its impacts on patterns of human settlement and density in four cities in Kentucky and Missouri.

Setbacks (also called no-build areas in some municipal codes) are simply buffers placed in certain spots to prevent unwanted encroachment of human structures into sensitive areas. In the cases studied here, these setbacks are applied to sinkholes, placing a buffer between the edge of a sinkhole and the point at which construction or land-disturbing activities are permitted to occur. This buffer zone is therefore intended to act as a passive means of protecting the karst system from the impacts of human settlement and of protecting human-built structures from the expansion of karst landforms. Polluting activities and land stress are kept away from the sinkholes, and new buildings are not permitted so near a sinkhole edge as to leave the structure vulnerable to sinkhole expansion. Use of setbacks as a technique for controlling development on karst terrains is not unusual: setbacks are found in communities in Kentucky, Tennessee, Missouri, Florida, Pennsylvania, New Jersey, and Virginia, among other locations (some examples can be found in codes of ordinances for Pasco County, FL; Lower Saucon, PA; Lexington-Fayette County, KY; and Springfield, MO, for example).

We might expect setbacks to have an impact on housing density because they work to limit the amount of developable land in the immediate vicinity. Any land enclosed by a setback is removed from that inventory, which in theory should result in larger parcels or more undevelopable lots. This line of thinking relies on two assumptions: First, that all sinkholes are correctly identified and properly catalogued; and second, that the ordinance is actually enforced by city government. This last factor is critical, as city government may have neither the resources nor the inclination to adequately enforce their own sinkhole ordinances.

In order to conduct a limited but representative examination of the impact of setbacks on housing density, we can interpret data drawn from four study areas in the central United States: Lexington-Fayette County, Kentucky; Louisville, Kentucky; Springfield, Missouri; and St. Louis, Missouri. All four of these study areas are underlain by geology favorable to the development of karst landforms. All four are urban: the smallest (Springfield) had a 2000 population of just over 150,000, while the largest (St. Louis) had a population of just over 360,000 that same year (U.S. Census Bureau 2006). These four sites met criteria for data availability, urbanization, and location (i.e., all within the same general region). Urban areas were selected for this analysis because the generally higher population and housing densities may make compliance with setback regulations more challenging. In rural areas where developable land is plentiful, such restrictions could be more easily complied with by relocating development to less sinkhole-prone areas, and impacts of setback ordinances on housing density patterns would likely be more difficult to detect.

Despite these similarities, these cities do differ in one important way. Lexington-Fayette and Springfield employ setback-style regulations to limit development near sinkholes. But while Louisville and St. Louis also have sinkholes within the city limits, neither uses setbacks as a means to control nearby development. Because of this difference in regulatory approach, we can compare trends in housing density changes between these two pairs of cities and perhaps identify the impact of setback ordinances on those trends.

How These Four Cities Approach Issues of Karst and Land Use

Kentucky in particular has a history of karst-related problems instigated by human actions. A combination of overenthusiastic land clearing and poor agricultural practices in the karstic Sinking Valley simultaneously increased runoff quantities and decreased drainage capacity, resulting in severe flooding problems (Dougherty 1983). As late as the 1920s and 1930s, the city of Bowling Green (which at that time had no manmade sewer system) used the caves beneath the city as a waste disposal system. Indeed, even today the city has only incomplete records regarding which homes are connected to the sewer system and which are not; it is entirely possible that some homeowners who think their homes have a working sewer connection are actually using old, malfunctioning septic tank systems instead, which pose severe threats to the caves and karst below (Crawford 2003). Also in Bowling Green, a segment of Dishman Road directly above the Mudderhorn Room of State Trooper Cave collapsed in 2002 because of the concentration of stormwater runoff and the rapid removal of sediments; the resulting sinkhole was 60 m wide and seven meters deep (Kambesis et al. 2004).

With this history in mind, it should be no surprise that some Kentucky municipalities have chosen to take a proactive regulatory approach to addressing karst issues. In Lexington-Fayette, issues of human-karst interaction influence the planning process from several different angles. In Chapter 2 of the county's comprehensive plan, protection of sinkholes is listed as an objective of the county's environmental framework. The comprehensive plan points to the presence of karst geology and recognizes importance of karst sensitivity to maintaining groundwater quality—in particular, as it relates to manure piles. Chapter 3 of the plan includes clusters of sinkholes in its definitions of Other Hazardous Areas, and karst areas are also included in the definition of Environmentally Sensitive Lands, as well as the accompanying overlay district.

Nearly 800 km to the west, karst and karst landforms are mentioned frequently in the Springfield comprehensive plan. For example, the plan notes the threat posed by karst to groundwater supplies in the Fulbright Spring area, a major source of Springfield's drinking water; it recommends limiting densities in certain karstic watersheds; it acknowledges the potential environmental problems of living on a fractured limestone terrain and recommends steps to mitigate these problems; and it recommends enacting setbacks for individual sinkholes in several sensitive locations. The plan's authors repeatedly urge the city to review and update its sinkhole ordinance to require the consideration of water quality concerns when permitting construction projects in sinkhole floodplains.

Lexington-Fayette attempts to control development in karst areas through zoning and subdivision ordinances. This generally means more extensive approval requirements for landfills in karst terrain and certain other uses located in karstic agricultural areas. Other controls include considering the presence of sinkholes in its tree protection standards (for example, according to the zoning ordinance, no tree may be removed from a sinkhole that will remain open space). In 1985, the Lexington-Fayette Urban County Government passed ordinance SRA 85-2, otherwise known as the Sinkhole Ordinance. While it is in some ways redundant to the county's zoning and subdivision ordinances, SRA 85-2 also approaches the issue of karst land use regulation in notably different ways. First, it establishes "non-buildable areas" around sinkholes. These non-buildable areas will usually "follow the limits of the sinkhole," but can be expanded or contracted as appropriate by the Planning Commission. The sinkhole ordinance restricts—but does not outright forbid—development in the sinkhole drainage area. Sinkholes can, in certain circumstances also be used for drainage purposes, but buildings may not be constructed on sinkhole fill.

Springfield's sinkhole ordinance was enacted four years later, in 1989, as a response to rapid urbanization and the stormwater runoff problems that came with it. It was hoped that this ordinance would prevent the discharge of potentially contaminated surface runoff into sinkholes and the aquifer below. While the ordinance requires additional steps in the permitting process for developments in sinkhole drainage areas, it is the setback/no-build component that most interests us here (Barner 1999). Like Lexington-Fayette's sinkhole ordinance, the non-buildable area specified by the Springfield ordinance generally does not extend beyond the limits of the sinkhole itself; any deviations from this standard can be implemented by local government.

While many karst regulations are enacted with the goal of protecting an aquifer or a unique and fragile cave system, neither was the primary goal of the Lexington-Fayette sinkhole ordinance. Instead, one of the more important motivations behind the passage of the Sinkhole Ordinance was to prevent future sinkhole-related legal actions against the county (Rebmann 2006). Because litigation reduction has a direct financial benefit to the city that ecological protection does not, it seems reasonable to assume that the Planning Commission would be more likely to resist pressure from landowners and developers to shrink non-buildable areas on the sites of proposed construction projects than they would be if the primary motivation behind the ordinance were cave preservation.

Determining the Relationship Between Sinkhole and Structural Densities

Theoretically, sinkhole setbacks should affect structural densities, for reasons explained earlier in this chapter. But is that the case? Do karst-related setback-style ordinances have any impact on housing density in areas where sinkholes are present? And if so, what is the nature of the impact? These are the questions this case study was designed to answer.

Because the effects that can answer these questions are more likely to be observable at a smaller scale, this analysis was conducted at the Census block level, the smallest geographic unit used by the Census Bureau. Shapefiles were obtained from several sources, including the U.S. Census Bureau, the Kentucky GIS office, and the Missouri Spatial Data and Information Service. Block-level housing data were obtained from the Census Bureau. Sinkhole location data came from the Kentucky Geologic Survey and the Missouri Department of Natural Resources. Table 4.1 summarizes the data used for this analysis.

Table 4.1 Summary of data used for setback regressions

Variable	Description	Mean	Std. Dev.	Min	Max
lnSQKM	Area of Census block, in square kilometers (natural log)	1.011	1.273	0.002	5.441
lnSinkDens	Number of sinkholes per square kilometer (natural log)	1.869	1.407	0.008	6.159
lnHousDens	Number of housing units per square kilometer (natural log)	3.716	2.662	0	8.334
Setbacks	Binary variable indicating the use of setback regulations	0.686	0.464	0	1
yr_2K	Temporal binary variable	0.565	0.496	0	1
DIDvar	Difference-in-differences binary variable	0.447	0.497	0	1

n = 695 for all variables

In this analysis, housing and sinkhole density data were included only for blocks in each city that contained sinkholes. This is because setback-style ordinances would only be an issue in blocks that actually contain sinkholes. For blocks without sinkholes, such regulation is moot, since there are no sinkholes to be concerned about. Additionally, it meant that potentially unmapped sinkholes that may have a detectable impact on density, but would themselves be invisible for purposes of this analysis, would not be a factor. Another reason for examining only blocks with sinkholes is that doing so helped ensure that roughly the same geographic areas were examined in the 1990 and 2000 data sets. Since Census geographies change with every Census, block boundaries are not constant and block-level data cannot be directly compared between Censuses. Table 4.2 enumerates sinkholes in each of the four municipalities.

The analysis used a simple calculation of the correlation coefficient between housing density and sinkhole density; an ordinary least squares (OLS) regression to determine the relationship between sinkhole density, housing density and the presence of karst-related setback ordinances at the block level; and a difference-in-differences regression to measure the change, if any, in that relationship between 1990 and 2000. The correlation coefficients and the OLS regressions were run separately for observations taken in 1990 and in 2000.

Several 1990 observations were dropped because housing data were not available for those particular blocks. This partially accounts for the different number of observations in 1990 and 2000; changes to Census geographies between 1990 and 2000 account for the rest.

Table 4.2 Sinkhole counts for each city in the study area

City	Number of sinkholes	Number of Census blocks (year 2000) that contain sinkholes
Lexington-Fayette County, KY	1017	217
Louisville, KY	39	17
Springfield, MO	181	95
St. Louis, MO	109	65

Running the Numbers

Two slightly different OLS regressions were run for this analysis. The first regression used the natural logarithm of housing density (*lnHDens*) as the dependent variable, with the natural logarithm of sinkhole density (*lnSinkDens*) and *setbacks* (a binary variable set to 1 in blocks where karst-related setback-style ordinances were in force) as explanatory variables. The second regression included the natural logarithm of block area in square kilometers (*lnSQKM*) as an additional explanatory variable (the natural logs of these variables were taken in order to normalize the data and make it more suitable to linear regression analysis). The *lnSQKM* variable was added to account for the fact that in some areas block size varied considerably, which could conceivably impart bias onto any analysis of density; this was of particular concern in Lexington-Fayette County, where many of the Census blocks outside the city's urban growth boundary are quite large.

Because Lexington-Fayette County's sinkhole ordinance dates back to 1985, the *setbacks* variable was set to 1 for all observations taken there in both 1990 and 2000; this is based on the assumption that five years was enough time for the setbacks to show at least some initial impacts on density. By contrast, Springfield's ordinance was passed in 1989; it seems unlikely that any density-related impacts would be strong enough to be observable by the following year. For that reason, Springfield's 1990 observations were assigned a *setbacks* value of 0, while the 2000 observations were assigned a value of 1. All observations from both St. Louis and Louisville were assigned a *setbacks* value of 0.

The difference-in-differences (DD) regression is designed to measure the difference in the rate of change of a given statistical relationship between two distinct groups of observations. In this case, those groups are blocks with karst-related setback-style ordinances in place and those without them. DD models are often used for detecting changes caused by a specific event or policy. This analysis does exactly this, using a DD model to capture changes over time to the relationship between housing density and sinkhole density in Census blocks where setback-style regulation is in effect.

In the DD regression used here, *lnHDens* is once again the independent variable, with *lnSinkDens*, *setbacks*, and *lnSQKM* included as explanatory variables. In addition to those, the DD regression also includes two other binary variables: *yr2k*, for observations taken in the year 2000; and *setbacks_yr2k*, which was created by multiplying *setbacks* by *yr2k*. This interaction variable captures the change in the relationship between housing density and sinkhole density between 1990 and 2000 for blocks in which sinkhole setbacks were applicable. In other words, if setback ordinances had any impact on the relationship between housing density and sinkhole density between 1990 and 2000—for example, by slowing housing density growth during that time in areas with higher sinkhole densities—this effect will be captured by this variable.

The correlation coefficient between the natural logarithms of housing density and sinkhole density was 0.6735, revealing a moderate amount of positive statistical correlation between both variables. Instinctively, one might expect a negative correlation between sinkhole density and housing density, since one might expect homebuyers to prefer to live further away from sinkholes. That this seems not to be the case is interesting and is explored further later in this chapter. At any rate, this statistical relationship seems to have weakened between 1990 and 2000. It is important to remember that this statistic is nothing more than a general measure of correlation between housing density and sinkhole density across the entire study area; the presence of setback regulations is not taken into account.

This positive correlation between sinkhole density and housing density is also evident in the OLS regression results (Tables 4.3, 4.4, 4.5 and 4.6). The *setbacks* variable is statistically significant in three of the four OLS models; additionally, the variable's coefficient has the expected negative sign in all four sets of results, which

Table 4.3 Ordinary Least Squares regression results

Model 1: regression using housing density (natural log) as the dependent variable, using year 2000 data.

Explanatory variables	Coefficient	Standard error	t value
lnSinkDens*	1.1085	0.0955	11.6
Setbacks	−0.3179	0.3408	−0.93
Constant	1.5479	0.3985	3.88

*=statistically significant at 0.01
n = 393
Adjusted $R^2 = 0.3802$
F = 121.21

means that housing densities are uniformly lower in blocks where karst setbacks are applied. The impact of these conflicting effects on housing density for sinkhole density (positive) and for setback ordinances (negative) are linked to sinkhole density; in blocks with lower sinkhole densities, the negative correlation is stronger. It is also interesting to note that the setbacks variable was more strongly significant for observations taken in 1990 than in 2000; this will be examined shortly.

Table 4.4 Ordinary Least Squares regression results

Model 2: regression using housing density (natural log) as the dependent variable and including area in square kilometers as an explanatory variable, using year 2000 data.

Explanatory variables	Coefficient	Standard error	t value
lnSinkDens**	0.5956	0.1347	4.42
lnSQKM**	−0.5918	0.113	−5.24
setbacks*	−0.5099	0.3318	−1.54
Constant	3.3121	0.5121	6.47

** = statistically significant at 0.01; * = statistically significant at 0.1
n = 393
Adjusted $R^2 = 0.4195$
F = 95.43

Table 4.5 Ordinary Least Squares regression results

Model 3: regression using housing density (natural log) as the dependent variable, using year 1990 data.

Explanatory variables	Coefficient	Standard error	t value
lnSinkDens*	1.1216	0.0869	12.89
setbacks*	−0.8378	0.2205	−3.8
Constant	2.5262	0.2946	8.57

* = statistically significant at 0.01
n = 302
Adjusted $R^2 = 0.5301$
F = 170.81

Table 4.6 Ordinary Least Squares regression results

Model 4: regression using housing density as the dependent variable and including area in square kilometers as an explanatory variable, using year 1990 data.

Explanatory variables	Coefficient	Standard error	t value
lnSinkDens**	0.654	0.9893	6.61
lnSQKM**	−1.4088	0.1785	−7.89
setbacks*	−0.4734	0.2061	−2.3
Constant	4.1847	0.3408	12.28

** = statistically significant at 0.01; * = statistically significant at 0.05
n = 302
Adjusted $R^2 = 0.6101$
F = 157.97

The DD regression tends to confirm the results of the OLS regression (Table 4.7). Here, all five explanatory variables are statistically significant, with the *lnSinkdens, lnSQKM* and *setbacks* variables showing the same signs they did in the OLS results (positive, negative and negative, respectively). The negative sign on the *yr2K* variable argues that, within the study areas, housing densities in Census blocks with sinkholes fell between 1990 and 2000 irrespective of the use of setbacks, a result that is weakly suggested by comparing coefficients between the two sets of OLS regression results. Finally, the coefficient on the *setbacks_yr2k* interaction variable is actually positive, counter to what we might expect—this suggests that housing density in blocks where setbacks apply actually *increased* relative to other blocks. Instinctively, we would probably expect to see density in these locations fall relative to blocks where setback regulations are not in force, particularly since housing density in the study areas as a whole actually fell during the 1990s.

Table 4.7 Difference-in-differences regression results

Dependent variable: housing density (natural log)

Explanatory variables	Coefficient	Standard error	t value
lnSinkDens*	0.7003	0.0854	8.2
lnSQKM*	−0.6309	0.0863	−7.31
setbacks*	−0.9743	0.2335	−4.17
yr2k*	−0.9412	0.2604	−3.61
setbacks_y2k*	0.7587	0.3202	2.37
Constant	3.9058	.03111	12.55

* = statistically significant at 0.01
n = 695
Adjusted $R^2 = 0.5145$
F = 148.09

What All These Numbers Mean

The analysis described above, while useful, does have its shortcomings. First, there is the question of *when* these sinkholes actually formed. The sinkhole location data used here were collected around the year 2000, instead of as they occurred; as a result, there is no way to tell whether a sinkhole was twenty years or twenty minutes old when the data were collected. It is possible that some of the sinkholes referenced in this analysis did not exist in 1990, which may make data on sinkhole densities in 1990 a bit less reliable. Second, different methods of displaying sinkhole location in GIS are used for the Kentucky and Missouri data, which may limit the extent to which they are directly comparable.

The statistical relationships described in this chapter suggest that setbacks do appear to be related to housing density in areas where sinkholes are present. The fact that housing densities in blocks with sinkholes and setback ordinances actually increased is interesting, especially since the time period examined here coincided almost exactly with the first decade after implementation of Springfield's sinkhole ordinance. It is interesting because it suggests that Springfield's sinkhole ordinance had no impact on housing density in sinkhole-prone areas during the 1990s: even if housing densities in Lexington-Fayette stayed the same—remember, their ordinance had already had four or five years to work—the interaction variable should have shown the rate of increase in housing densities to be decreasing as setbacks are applied to larger segments of the study area. If this interpretation is correct, it still leaves unanswered the question of whether the regulations are actually ineffective or simply unobtrusive.

Another factor with the potential to affect this analysis is the urban service area (USA) that rings the urbanized section of Lexington-Fayette County. The USA was first defined in an amendment to the 1958 comprehensive plan as a method of controlling urban growth and protecting the region's famous horse farms from urban encroachment (Fleming 2001). It acts as a growth boundary by imposing a minimum lot size beyond its borders; the definition of this area is provided by a map contained within the comprehensive plan.

Originally, the USA was simply a line beyond which the city would refuse to provide services such as water, electricity, roads, schools or sewer. But it did not work particularly well, at first mostly because of a fragmentation effect: new developments that relied on septic systems (and thus able to go without access to the city's sewer system) continued to spring up in rural Fayette County (Carruthers 2002). This began to change only with the merger of the governments of the City of Lexington and Fayette County in 1973. At that point, a minimum lot size beyond the USA of ten acres per lot was implemented; this was increased recently to 40 acres per lot in an effort to stop the phenomenon of "estate sprawl" (Fleming 2001).

In general, the goal of implementing an urban service area or urban growth boundary is to keep development constrained within a limited geographical area. However, that doesn't stop an urban area from adding population. All things being equal, when this growth is contained within a non-expandable geographic area, it theoretically will lead to smaller residential lots and higher land rents (Alonso

1964; Mills 1972). This general concept is a bit more complicated in the case of Lexington-Fayette because of the USA. As discussed earlier, in a city with no urban service area boundary, the predicted effect of a sinkhole ordinance would be more rapid outward growth of the urban area, with larger residential lots to compensate for the loss of buildable square footage. But the USA boundary puts opposite pressures on urban growth, acting as a method of confinement and limiting growth (Ambrose 2003).

Ultimately, what we have in Lexington-Fayette is a city that wishes to restrict outward growth and instead redirect it inwards, while at the same time limiting the intensity of development in sinkhole-prone areas within the city. The regulations used to achieve these goals should have conflicting effects on population and structural density: one works to increase density, while the other would have lower density as a side effect, at least in some areas. Could the fact that so many sinkhole-containing blocks are located in an area with an artificial constraint on the supply of buildable land have imparted any bias onto the results?

At least two factors suggest otherwise. For one thing, the majority of Lexington-Fayette sinkholes occur outside the USA: out of a countywide total of 936 mapped sinkholes, only 200 are found within the USA. Secondly, if the USA were actually a factor, one would expect setbacks to have a weaker effect—or none at all—on housing density because of the density-increasing effect of the USA.

Finally, why might we see positive correlation (in other words, as one statistic gets larger or smaller, the other follows) between sinkhole densities and housing densities? One possible explanation is reporting bias: sinkholes in highly populated areas may be more likely to be reported than those in areas with fewer people. However, because sinkhole location data from both states were compiled from USGS topographical maps, reporting bias is an unlikely explanation. It is also possible that karst features are being plugged and used as water features in new residential developments, where they would be more likely to be seen as amenities and not as hazards. One should not ignore the possibility that higher housing densities may bring higher sinkhole densities with them—as discussed in Chapter 1, we do know that human populations can place enough stress on karstic terrains to create new sinkholes. But without some knowledge of when individual sinkholes formed, it is extremely difficult to test this hypothesis.

This case study examined a direct relationship between sinkholes, setbacks and densities. In the next case study, we will explore a more indirect, but no less potentially important, relationship: the relationship between karst regulations and local economic health.

Case Study 2: Strategic Behavior in the Development of Karst Regulations: Does It Pay Off? A Case Study from Pennsylvania

Karst systems are shared resources. But because these systems do not recognize administrative or jurisdictional boundaries, karst-related problems generated by human activities in one municipality can easily spread to affect neighboring communities. If all communities connected to a particular karst system implement regulations intended to protect it, costs are shared by the people who enjoy the benefits those regulations bring. However, as we saw in Chapter One, it is sometimes thought that karst land use regulations carry high costs, in terms of lost opportunities for economic growth. This could encourage some communities to try to avoid these costs by refraining from implementing karst-related land use regulation, while reaping the benefits of neighboring communities' efforts at karst protection. This is what is known in economics as the *free rider* problem (see Varian 1992). But is such a strategy worthwhile? Using socioeconomic and regulatory data from cities and towns in karstic areas of Pennsylvania, this case study examines the question of whether towns that do not implement karst regulations enjoy an economic advantage over towns that do.

South-central Pennsylvania and Its Karst

The study area for this case study runs southwest from the Lehigh Valley to the Maryland border. The Lehigh Valley is located in eastern Pennsylvania, approximately 60 miles north of Philadelphia and 90 miles due west of New York City. The region is in a valley of the Appalachian Mountains, with areas of relatively high relief along the northwestern and southeastern edges. At the center of the Lehigh Valley are Lehigh and Northampton counties. Both counties are highly urbanized—taken together, they had a population of about 579,000 in 2000 (U.S. Census Bureau 2006), with an economic base that was once highly industrial. Socioeconomic statistics are pretty uniform across the region. Centers of population include the cities of Allentown, Bethlehem and Easton; combined, Lehigh and Northampton counties have 62 municipalities. Forty-two of these (Table 4.8) are at least partially underlain by carbonate bedrock, which has led to the development of karst landforms in the area (Lehigh Valley Planning Commission 2005).

To the southwest is Berks County, which is not usually considered to be part of the Lehigh Valley region but is included here because its urbanized nature and extensive karst are characteristics it shares with Lehigh and Northampton counties. Berks County had a population of roughly 373,000 in 2000, which is larger than the population of either Lehigh County or Northampton County that year. Nearly 80,000 of Berks County residents lived in Reading, the county's largest city. Berks County contains 76 municipalities within its boundaries, many of which have implemented at least some level of karst-related land use regulation (U.S. Census Bureau 2006).

The remaining three counties in the study area—Cumberland, Franklin and Lancaster—are located along the western edge of Pennsylvania's karst belt, toward the center of the state and extending to the Maryland state line (Fig. 4.1). While Cumberland and Franklin counties are smaller in terms of population than the counties in the Lehigh Valley (with populations of 213,000 and 129,000 in 2000, respectively), Lancaster County has the highest population of any in the sample: nearly half a million people lived there in 2000. Franklin County's largest city is Chambersburg, with a 2000 population of just under 18,000 (Table 4.9).

Table 4.8 Municipalities in Lehigh and Northampton Counties underlain by karst

Portland	Allentown
Upper Mt. Bethel	Hanover (Lehigh)
Lower Mt. Bethel	Catasauqua
Forks	North Catasauqua
Stockertown	Northampton
Tatamy	Coplay
Palmer	Whitehall
Nazareth	North Whitehall
Upper Nazareth	Upper Saucon
Lower Nazareth	South Whitehall
Easton	Emmaus
West Easton	Upper Macungie
Wilson	Lower Macungie
Williams	Macungie
Glendon	Lower Milford
Bethlehem Twp.	Upper Milford
Bethlehem City	Alburtis
Freemansburg	Weisenberg
Hellertown	Salisbury
Allen	Hanover (Northampton)
East Allen	Fountain Hill

The southeastern quarter of Pennsylvania contains part of a long band of karst topography that begins in Missouri and Arkansas and stretches eastward and northward, all the way to New Jersey and New York. Throughout Pennsylvania's carbonate bedrock band, conditions are suitable for karst topography to develop, and landforms like sinkholes, springs and caves are common (Kochanov 1999). Sinking streams are another feature commonly found in Pennsylvania's karstic zones, often running considerable distances before disappearing into the earth. Leakage from storm sewers and water mains are common drivers of sinkhole development in southeastern Pennsylvania, and sudden surface collapse is often the result, sometimes with near-disastrous results (see Kochanov 1999; Gillespie 1999; Memon et al. 2001; Memon et al. 2002).

Karst accounts for nearly the entire drainage system in some southeastern Pennsylvania communities, where karst aquifers are the source of groundwater (Chichester 1996; Kochanov 1999). In Northampton's Limestone Belt, it is estimated that more than half of all precipitation finds its way into the bedrock system below. Often there is no surface runoff, as the area's sinkholes are very well-developed in places. For example, between Monocacy and Bushkill Creeks, and between Monocacy and Catasauqua Creeks, there is little if any surface drainage: nearly every drop of surface water disappears into the underground drainage system (Miller et al. 1939).

There are serious problems with both water supply and water quality in some of the study area's limestone regions. Because groundwater flows through—and is concentrated in—defined open channels created by solution processes, a well driller has to actually hit one of these channels to get access to the groundwater. And

Fig. 4.1 Mapped karst points in the six counties of the Pennsylvania study area (see color plate 35)
Source: U.S. Census Bureau, Pennsylvania Department of Conservation and Natural Resources

even if a channel is struck, these waters are easily polluted from the contaminants carried by surface runoff: as early as 1940, many shallow household wells were being abandoned for exactly this reason (Miller 1941). More recently, water drawn from wells in the area was found to contain high levels of coliforms, streptococcus bacteria, and *e. coli*. These higher concentrations of *e. coli* showed a statistically significant positive correlation with the presence of carbonate bedrock (Bickford et al. 1996). Nitrate levels in the carbonate aquifers of agricultural areas exceeded those found in local surface waters, as well as in carbonate aquifers in urbanized zones; this is probably related to more intensive use of nitrate-based fertilizers for agriculture (Hippe et al. 1994; Lindsey et al. 1997).

Table 4.9 Year 2000 demographic data for the six Pennsylvania counties in the study area

County	Population	Median household income	Median home value	Population in poverty (pct)	Population with college degree (pct)
Berks	373,638	$44,714	$104,900	9.4	18.5
Cumberland	213,674	$46,707	$120,500	6.6	27.9
Franklin	129,313	$40,476	$97,800	7.6	14.8
Lancaster	470,658	$45,507	$119,300	7.8	20.5
Lehigh	312,090	$43,449	$113,600	9.3	23.3
Northampton	267,066	$45,234	$120,000	7.9	21.2

Source: U.S. Census Bureau fact sheets

Land Use Regulation in Pennsylvania and How Karst Relates

Growth and development across the karstic regions of Pennsylvania is generally managed by one of three regulatory tools: a subdivision and land development ordinance (SALDO), a zoning ordinance, or a comprehensive plan. However, while the first two have the force of law behind them, the comprehensive plan is somewhat weaker. The state planning code notes that an act of government shall not be declared invalid or subject to challenge on the sole basis that it is inconsistent with the adopted comprehensive plan. In other words, a comprehensive plan is for guidance only, even though zoning ordinances are supposed to work to promote the goals and objectives of the comprehensive plan. Because they do not carry the same force of law as a local zoning ordinance or SALDO, comprehensive plans are not included in the analysis that follows this section and are mentioned here only for the sake of completeness. In some cases, all three are used in a complementary manner so as to achieve the maximum level of protection possible.

The importance of karst geology is acknowledged in comprehensive plans across the region. The Lehigh Valley Comprehensive Plan, for example, sets forth two policies related to sinkholes: one, that developments should be designed in such a way as to minimize the occurrence of sinkholes and sinkhole-related problems; and two, that municipalities on carbonate bedrock develop sinkhole management programs. The plan also recommends adopting SALDOs to manage development in carbonate areas, as well as subdivision ordinances designed to mitigate risk posed by sinkholes. However, some comprehensive plans make no effort to address karst as a factor in planning for future growth: while the Berks County Comprehensive Plan mentions karst as a factor in generating development pressures, nowhere does it describe any policies intended to address the issue. It is also important to remember that policies and recommendations put forth in a comprehensive plan are not legally binding upon the municipalities subject to them (Pennsylvania Planning Code 1967), which is a common limitation of comprehensive plans across the United States.

Many counties in Pennsylvania have implemented their own SALDOs and zoning ordinances. Under state law, these countywide regulations apply only to municipalities without their own ordinances: the Lehigh Valley Comprehensive Plan notes that while "municipal plans are required to be generally consistent with the adopted county plan … *county comments cannot override local zoning*" (Lehigh Valley Planning Commission 2005, p. 51) (emphasis mine). In other words, local governments in Pennsylvania have the power to override county governments on subdivision, land development, and zoning issues. In practice, this can mean that county-level ordinances are applicable in only small portions (i.e., boroughs and townships without similar or contradictory regulations) of the county that passed them, since counties in Pennsylvania are completely divided into smaller jurisdictions (townships, boroughs and cities): there is no "unincorporated" land that rely exclusively on county ordinances for management. This is a distinct difference from the situation in some other heavily karstified states like Florida, where large population centers in unincorporated areas are common.

It is difficult to identify any shared characteristics of municipalities that choose to regulate human activities on karst landscapes in Pennsylvania. According to an examination of online municipal codes and data provided by the Pennsylvania Department of Conservation and Natural Resources (DCNR), municipalities with mapped karst are just as likely to have chosen not to implement karst land use regulations as they are to have chosen to do so. Figure 4.2 is a map generated from a sample of cities and towns in the region. Within that sample, there were 42 municipalities with mapped karst points in which no karst land use regulations were found and 43 with mapped karst points where those regulations are in use. There also does not seem to be any correlation between the level of urbanization of a municipality and the likelihood of finding karst-related regulations or ordinances on the books. It is true that Allentown, the city with the highest population in the sample, does have a weak form of karst regulation on the books; however, the cities of Reading (with a population near 80,000 in 2000), Bethlehem City (approximately 70,000) and Lancaster (approximately 50,000) do not even provide the minimal level of karst protection that Allentown does.

Clearly, cities and townships in Pennsylvania have a wide degree of latitude when it comes to implementing land use regulations that affect development near karst landforms. This flexibility is reflected in the variety of regulatory techniques in use. Table 4.10 displays a summary of techniques used to regulate development on karst by municipalities in the sample. The most commonly used techniques for regulating land use and development in karst terrains are stormwater-related components (in particular, more stringent design standards for stormwater retention basins), and requirements for inclusion of karst landforms in development plans at the sketch, preliminary or final plan stages. Intuitively, it may seem that the zoning overlay approach would be the approach that's most effective and easiest to manage in this context. However, very few jurisdictions in the sample actually use it: Lower Saucon and Lower Macungie include karst or carbonate geology overlay zones in their zoning ordinances, while a handful others use more general overlay districts that affect development in karst areas but are not karst-specific. Several municipalities in the study area explicitly claim powers to reject or stop projects that do not meet certain karst-related requirements, often as part of their SALDO. Often this is related to a

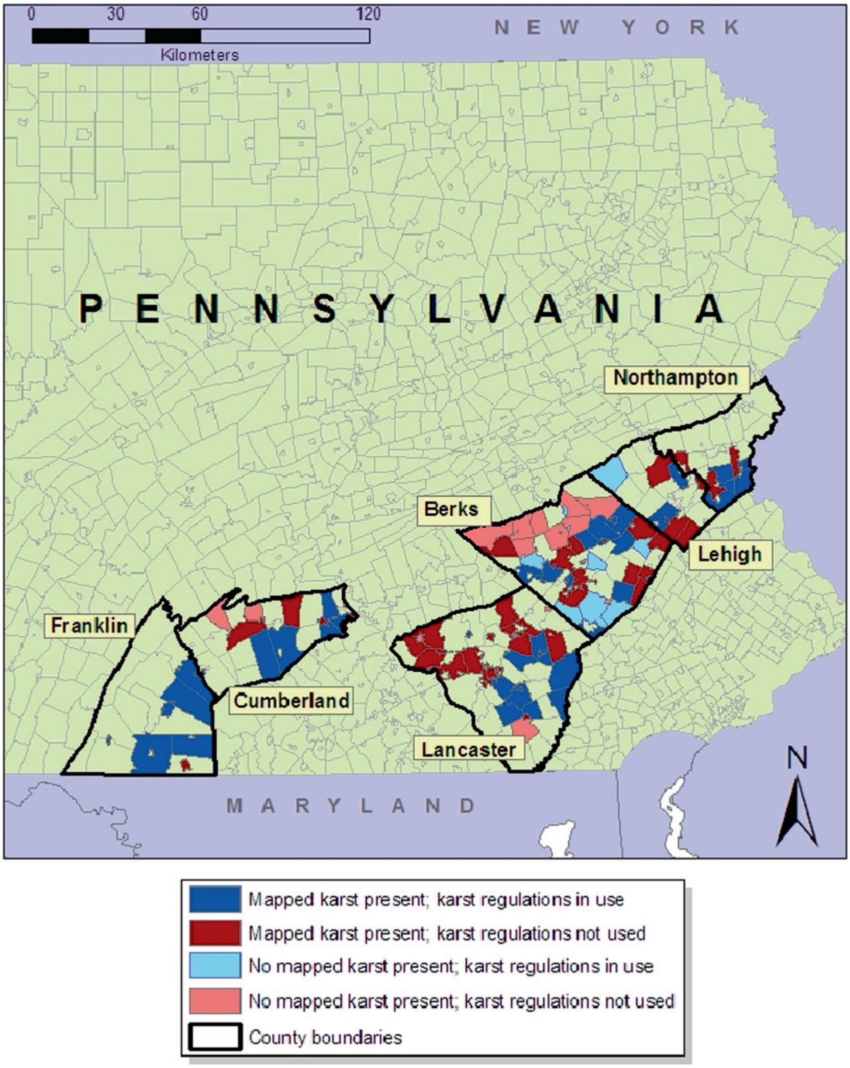

Fig. 4.2 Distribution of karst and regulation practices in selected Pennsylvania municipalities (see color plate 36)
Source: U.S. Census Bureau, Pennsylvania Department of Conservation and Natural Resources, individual municipal codes

declaration of unsuitability for building on a particular plot, a declaration which can usually be addressed and then changed.

There is often no clear distinction between regulatory techniques that are used in SALDOs and those that are used in zoning ordinances. There are exceptions—zoning overlays and Planned Residential Development regulations are only used in

Table 4.10 Municipalities included in the sample where land use in karst terrains faces additional regulations or management

	SALDO	Zoning	Regulatory techniques used
Allentown city	N	Y	Planning, stormwater
Alsace township	Y	N	Planning, design
Amity township	Y	Y	Planning, hazard
Antrim	Y	N	Planning
Bechtelsville borough	Y	Y	Planning, design, setbacks, stormwater
Bethlehem township	Y	Y	Planning, stormwater
Boyertown borough	Y	N	Planning, design, stormwater
Brecknock township	Y	N	Design, stormwater
Caernarvon township	Y	-	Planning, design
Camp Hill	N	N	Other
Carlisle	Y	N	Planning
Dickinson	N	N	Other
District township	N	Y	Other
East Allen township	Y	N	Planning, design, setbacks, stormwater
East Pennsboro	Y	N	Planning, design, hazard
Easton city	N	Y	Planning
Exeter township	Y	N	Planning, other
Hamburg borough	Y	N	Design
Hampden	Y	N	Design
Heidelberg township	Y	Y	Planning, other
Kutztown borough	Y	N	Planning, design, stormwater, other
Lower Allen	Y	Y	Planning, design
Lower Heidelberg township	Y	-	Planning
Lower Macungie township	Y	Y	Planning, setbacks, zoning overlays
Lower Saucon township	Y	Y	Planning, design, stormwater, zoning overlays, setbacks
Lynn township	Y	Y	Planning
Maidencreek township	Y	N	Design
Maxatawny township	N	Y	Planning
Mercersburg	Y	N	Hazard
Muhlenberg township	Y	Y	Planning, design, stormwater, zoning overlays
New Morgan borough	Y	N	Other
North Heidelberg township	Y	Y	Planning, other
North Middleton	N	Y	Planning
Pike township	Y	N	Planning
Quincy	Y	N	Planning, stormwater
Richmond township	Y	N	Planning, design, stormwater
Robeson township	Y	Y	Planning, design
Robesonia borough	N	Y	Other
Rockland township	Y	N	Design
Shillington borough	Y	-	Planning, design, stormwater
Shippensburg	Y	N	Planning, design, setbacks, hazard
Shippensburg Township	Y	N	Planning
Shoemakersville borough	Y	N	Planning, design, stormwater
Silver Spring	N	Y	Planning
South Middletown	Y	Y	Planning, design, setbacks, stormwater
Southampton	Y	N	Planning
Strausstown borough	Y	N	Design
Walnutport borough	Y	N	Planning

Table 4.10 (continued)

	SALDO	Zoning	Regulatory techniques used
Washington	Y	N	Planning, hazard
Wernersville borough	Y	-	Planning, design, stormwater
Whitehall township	Y	N	Planning, other
Williams township	Y	N	Planning
Wilson borough	Y	N	Planning
Womelsdorf borough	N	Y	Other
Wyomissing borough	Y	-	Design, stormwater
Wyomissing Hills borough	Y	-	Planning, design, stormwater

zoning ordinances, for example—but the fact that some regulatory are found in both types of ordinances in different towns suggests that the main difference may be in how stringently a municipality wants or intends to enforce the karst regulations.

Finally, many karst-related land use ordinances are very similar, if not identical, to those found in the codes of other towns in the area. For example, several different towns have identical or nearly identical statutory language addressing retention basin issues. Other towns have passed identical ordinances relating to groundwater contamination and spring flow, preventing subsidence-related damage, and the power to deny unsatisfactory applications based on karst-related requirements (in fact, it is not uncommon for municipalities to share precisely this regulatory language). This suggests at least two possibilities: one is that towns are simply copying ordinances used by their neighbors; another is that these ordinances all have another common source, like the Northern New Jersey Model Ordinance.

Strategic Behavior and Land Use Regulation

As discussed, regulating development in karst areas—and particularly in the vicinity of karst landforms—is an important tool for protecting local aquifers. In an area like the Lehigh Valley, where there are dozens of municipalities of vastly different size, groundwater contaminated in one township does not stay within the township lines. It also seems clear that aquifer protection is at least one major goal of the area's karst regulations, because drainage and runoff into sinkholes is a frequently addressed issue within these regulations.

However, simple game theory would suggest that it is in the interest of any township not to regulate development near karst landforms. In theory, karst regulations drive up the cost of development, both to the developer (who must spend more time investigating potential project sites and more money on mitigation) and to the town (which must spend more money enforcing its karst ordinances and hearing appeals from developers whose projects have been turned down). These ordinances may also have another cost to municipalities—the cost of lost growth opportunities as developers choose to build in lower-regulation, lower-cost neighboring towns. In effect, jurisdictions with karst regulations on the books would then be paying the entire cost of protecting the regional groundwater supplies, while non-regulating towns would be free to undo that protection and attract new development opportunities that have chosen to bypass regulating communities. Put another way, if a small township like Lower Saucon cannot influence what its neighbors choose to do to regulate development near sinkholes or other karst features, what incentive does it have to implement its own karst regulations?

Intuitively, it would seem that this patchwork approach enables developers to "play one town against the other" when selecting a location for a large project and that the sensible decision for any town hoping to encourage growth would be to implement no karst development regulations at all. Yet despite this, many of the municipalities in the Lehigh Valley do indeed regulate development on and near karst landforms.

This situation leads us to an interesting question that may have significant implications for understanding how karst land use regulations really work: When considering the future of the implementation of karst-related land use ordinances, should land use planners and public officials take into account whether or not neighboring communities have already implemented similar regulations? Do non-regulating towns enjoy any growth-related economic benefit at the expense of towns that choose to regulate development near karst? Or are karst regulations basically neutral as far as growth and development questions are concerned?

Applying statistical methods to data collected from the U.S. Census Bureau, the Department of Housing and Urban Development, and from the land use regulations of municipalities in the sample can help find evidence of a relationship between the presence of karst regulations and economic health and growth. Of course, there is no single statistic that represents overall economic health or growth, especially at the local level. For that reason, certain localized economic indicators have to stand in as proxies for overall economic growth and health. After considering several indicators for inclusion in this analysis, two were eventually chosen: the total number of residential construction permits issued for each jurisdiction between 1990 and 2000 and the change in median housing value over that same time. These variables were chosen because they were easily quantifiable, they were available for nearly every municipality in the sample and there is a clear hypothetical connection between both of them and the presence of karst land use regulation (this was not the case for most other economic prosperity indicators: for example, it may be the case that the presence of karst regulation results to higher unemployment rates in towns that implement those regulations, but it is difficult to imagine a credible and direct mechanism by which that might occur).

There are two general schools of thought regarding the impact of land use restrictions on home values: one is that the restrictions on the homeowner's ability to use private property in whatever way he or she sees fit will be accounted for in the home's total value (as a decline, usually), while the other approach holds that because land use restrictions can act to preserve the character and natural amenities of an area in which they are applied, they can just as easily have a positive impact on home values (McCann 2001). Assuming that both effects are possible, it seems more likely that karst regulations would have a positive impact on home values than a negative one. This is based on the fact that karst-related land use regulations often act to indirectly encourage preservation of open space and the natural environment and to promote lower development densities.

The total number of residential construction permits issued between 1990 and 2000 can be used to identify any effect on building and development patterns that karst land use regulations may have caused. Because karst-related land use regulations often add steps (and expense) to the development process—and in some cases, can stop a development in its tracks—it is likely that we may see some direct impacts of such regulation reflected in the number of residential permits granted in towns with these ordinances on the books, as developers seek out locations with fewer obstacles to new projects. In other words, the presence of karst regulations, and in particular strong karst regulations, should act to depress the number of permits issued relative to municipalities that do not use such regulations.

The sample itself contains observations taken in cities and towns located in six different Pennsylvania counties: Berks, Cumberland, Franklin, Lancaster, Lehigh and Northampton. These counties range from mostly urbanized to mostly rural; the common thread linking all seven is the presence of significant karst within their borders, which means that at least some towns located within these counties could be expected to have some type of karst-related land use regulation on the books.

Taken together, these six counties contain 253 individual municipalities, according to the U.S. Census Bureau. Many of these cities and towns were not included in the sample used for these regressions. Exclusion from the sample was based on one of two general criteria: timing (relevant zoning ordinances or SALDOs had to be in place by 2000; those with unclear dates of implementation were excluded), and data availability (the sample includes towns with both SALDOs and zoning ordinances available online and towns with only one set of regulations available online, provided these available ordinances contained karst-related provisions and that these karst provisions could be categorized as strong). These documents are not universally available online for every city and township in Pennsylvania, and by including only communities that have made these documents available online, there may have inadvertently been some amount of bias introduced into the results. However, no obvious pattern could be detected to explain why some communities chose to make these documents available in electronic format and others did not. This resulted in a sample size of 120, which is 47.4% of the population of 253.

The questions of the economic impacts of karst land use regulation and the utility of free riding are addressed here through ordinary least squares regression techniques. Variables describing characteristics such as population, population growth, urbanization, changes in median rents, and home size were included as controls. Additionally, binary ("dummy") variables were used to account for the presence of mapped karst points within the town limits (*MappedKarst*), the presence of karst regulations in each city or township (*KarstRegs*), and the strength of these karst regulations (*strong*). Finally, by multiplying *KarstRegs* and *MappedKarst* for each observation, a fourth dummy variable was created. The point of creating this interaction variable is to identify communities that have both mapped karst points within their boundaries and karst land use regulations on the books.

Because these regressions rely heavily on these dummy variables, an explanation of how they were developed is in order. First, keyword searches of electronic-format documents helped identify karst-related provisions in SALDOs and zoning ordinances. All "hits" were investigated; several did not relate to land use, and many others were "false positives" (for example, searches on the keyword "carbonate" sometimes returned results addressing the business practices of termite exterminators). All relevant results were then inventoried by city; this inventory is the basis for the *karstregs* variable.

The *strength* variable is not quite as straightforward as that. In the context of this chapter, the strength of a regulation is directly related to its potential to significantly influence the decision to build or not build in a given town. Strong regulations display one of the following characteristics: a section specifically set aside to address development in karst or carbonate areas, explicit power to stop or reject a development based on karst-related issues, or generally applied setbacks. Those classified as "weak" lack these features (repeated use of the word "may" in a karst context, instead of "shall" or "must," was another common feature of weak regulations). Categorizing a set of ordinances as weak or strong was, first and foremost, a subjective process; in some cases, a collection of individually weak requirements was classified as strong, based on the overall potential for impact on the development process. However, the criteria used were applied consistently to all ordinances in the sample and should at least be a useful gauge of relative regulatory strength. In the end, the key question in determining whether a set of regulations was strong or weak was this: might a particular set of regulatory requirements be onerous enough to make a developer think twice about building on a given piece of land with karst-related issues?

Running the Numbers: Is Strategic Behavior Good Strategy?

The regressions found one statistically significant relationship between a variable of interest and a dependent variable: the interaction variable was found to have a statistically significant relationship to the total permits issued dependent variable (Table 4.11). However, the coefficient is positive, meaning that total permits issued were higher in communities that had both mapped karst points and karst-aware land use regulations. This significance disappears when the *strong* variable is dropped from the model (Table 4.12); there was also no statistically significant relationship discovered between the change in median housing value dependent variable and any of the binary variables of interest (Tables 4.13 and 4.14). Further, the differences in R^2 values demonstrates that while the model does explain a respectable amount of the variation in total permits issued, it is not especially useful in explaining changes in median home values.

These results argue forcefully against the idea that the presence of karst regulations has much of an effect on development, at least with respect to the residential market, or on median home values. It therefore follows that towns choos-

Table 4.11 Ordinary Least Squares regression results

Model 1: ordinary least squares regression with robust standard errors, using total residential building permits as the dependent variable

Explanatory variables	Coefficient	Standard error	t value
Total population, 1990 *	.0148708	.0059324	2.51
Population growth rate, 1990–2000 (percent) *	12.75187	2.810637	4.54
Change in percentage of "long-distance" commuters	−3.653832	5.864986	−0.62
Growth rate of urban housing units	1.811643	1.3552	1.34
Rate of change in the percentage of "large" homes *	22.50077	9.33764	2.41
Change in median gross rent, 1990–2000	.2378838	.4161294	0.57
Change in median housing value, 1990–2000	−.0039291	.0034126	−1.15
Karst regulations present?	−69.8021	87.08814	−0.80
Karst regulations classified as "strong"	13.10388	139.6921	0.09
Mapped karst points present?	77.51629	66.51265	1.17
*Interaction variable (both regulations and mapped karst points are present) **	264.1354	138.5633	1.91
Constant	−29.41458	49.66519	−0.59

Variables of interest *in italics*
* = statistically significant results at 0.10
n = 105
Adjusted R^2 := 0.4673

ing to implement karst-related land use regulation are not putting themselves at a disadvantage in competing for development and growth opportunities with their non-regulating neighbors.

There are several possible explanations for these results:

- Development pressures may be causing the development of mappable karst features. This hypothesis was also advanced as a potential explanation of the results in the first case study and would explain the positive coefficient on the interaction variable in the first regression (Table 4.11);
- Karst protections may act to increase the desirability of living (and thus the demand for available housing) in a community that employs them, by forcing more land to remain open and undeveloped;
- Even the strongest karst regulations may not really be that onerous. We know from the regression results that the strength of karst regulation did not have an impact on the indicator variables for jurisdictions in the sample. When combined with the knowledge that the presence of karst regulations also had no impact, perhaps this can be taken to mean that karst regulations and ordinances generally aren't very restrictive and cannot counteract the influence of market forces;
- The lack of impact of karst ordinances could be a reflection of a lack of enforcement. Certainly, variances and waivers can be obtained in most jurisdictions; whether there is a lack of will to regulate in this case is unclear and beyond the scope of this chapter; and

Table 4.12 Ordinary Least Squares regression results

Model 2: ordinary least squares regression with robust standard errors, using total residential building permits as the dependent variable

Explanatory variables	Coefficient	Standard error	t value
Total population, 1990 *	0.0146225	0.0058305	2.51
Population growth rate, 1990–2000 (percent) *	11.19164	2.841066	3.94
Change in percentage of "long-distance" commuters	−3.893057	5.765894	−0.68
Growth rate of urban housing units	1.727809	1.458323	1.18
Rate of change in the percentage of "large" homes *	16.4858	9.322062	1.77
Change in median gross rent, 1990–2000	0.0311469	0.3794541	0.08
Change in median housing value, 1990–2000	−0.0045279	0.0034124	−1.33
Karst regulations present?	*−72.97573*	*79.97385*	*−0.91*
Mapped karst points present?	*70.12362*	*68.48701*	*1.02*
Interaction variable (both regulations and mapped karst points are present)	*201.7053*	*129.5102*	*1.56*
Constant	0.1563617	49.39859	0.00

Variables of interest *in italics*
* = statistically significant at 0.10
n = 112
Adjusted $R^2 = 0.4051$

Table 4.13 Ordinary Least Squares regression results

Model 3: ordinary least squares regression with robust standard errors, using change in median home value as the dependent variable

Explanatory variables	Coefficient	Standard error	t value
Total population, 1990	−0.1233191	0.0829727	−1.49
Population growth rate, 1990–2000 (percent)	112.6703	93.63839	1.20
Growth rate of urban housing units	−10.87793	64.47095	−0.17
Change in percentage of "long-distance" commuters	−327.9395	267.3179	−1.23
Change in population with bachelors degree (percentage) *	−749.3715	405.4695	−1.85
Rate of change in the percentage of "large" homes	557.9663	380.3822	1.47
Change in median gross rent, 1990–2000	18.80939	13.12235	1.43
Karst regulations present?	*−1176.088*	*4287.548*	*−0.27*
Karst regulations classified as "strong"	*−6893.434*	*4317.497*	*−1.60*
Mapped karst points present?	*−3734.006*	*3321.258*	*−1.12*
Interaction variable (both regulations and mapped karst points are present)	*2940.861*	*5368.743*	*0.55*
Constant	5435.561	3458.283	1.57

Variables of interest *in italics*
* = statistically significant at 0.10
n = 105
Adjusted $R^2 = 0.1732$

Table 4.14 Ordinary Least Squares regression results

Model 4: ordinary least squares regression with robust standard errors, using change in median home value as the dependent variable

Explanatory variables	Coefficient	Standard error	t value
Total population, 1990	−0.1406539	0.0861091	−1.63
Population growth rate, 1990–2000 (percent)	122.9927	82.45413	1.49
Growth rate of urban housing units	−3.222844	61.00146	−0.05
Change in percentage of "long-distance" commuters	−283.8614	254.122	−1.12
Change in population with bachelors degree (percentage) *	−796.6282	380.1347	−2.10
Rate of change in the percentage of "large" homes *	783.9302	354.0678	2.21
Change in median gross rent, 1990–2000	18.1366	12.2212	1.48
Karst regulations present?	*−3165.006*	*4070.196*	*−0.78*
Mapped karst points present?	*−3790.971*	*3315.346*	*−1.14*
Interaction variable (both regulations and mapped karst points are present)	*3071.677*	*5188.513*	*0.59*
Constant	5314.729	3395.833	1.57

Variables of interest *in italics*
* = statistically significant at 0.10
n = 120
Adjusted $R^2 = 0.1715$

- Timing may be a factor. It seemed plausible that the short-term impacts of enacting this type of regulation could be different from the long-term effects—perhaps it takes a few years for karst regulations to make a noticeable impact on these indicator variables. By including a dummy variable indicating the year a karst ordinance was enacted, such a relationship could be identified. Unfortunately, this goal was out of reach for this analysis, because there was no way to determine the actual enactment date with any degree of certainty. It is possible that this could be done using different data and is a worthwhile direction for future research.

At first glance, the two case studies included in this chapter may appear to be too different from each other to tell us anything useful about karst land use regulation. But a closer look reveals that they are actually related in that they seek to understand how karst land use regulations affect the lives of the people subject to them, in a non-karst context. In other words, with these case studies we are not trying to determine if these regulations actually prevent people from dumping trash into sinkholes or pouring used motor oil on their lawns. We are instead trying to determine the true cost of implementing karst land use regulations, in terms of restrictions on how land can be used, impacts on urban densities, and general economic impacts.

When viewed that way, these two case studies, taken together, can indeed tell us something worth knowing: specifically, that there is a distinct lack of clear evidence that karst land use regulations directly or significantly impact the people living with them. It is true that the evidence regarding impacts on density is mixed: for example, when housing densities in sinkhole-prone areas are compared between municipalities that employ setback-style ordinances for sinkholes and those that do not, we see that structural density in these areas is lower in cities with setback ordinances. However, we do not see this differential increasing over the 10-year period studied here, which is the result we might have expected to see; instead, we actually see the opposite situation, where housing densities in sinkhole-prone areas with setbacks increase more quickly than in similar places without setbacks. This suggests that new residential construction in sinkhole-prone areas grew in the 1990s independently of whether or not setback regulations were in place. This would seem to have more to do with desirability questions not related to karst; i.e., the wide range of factors affecting neighborhood quality or the attractiveness of a larger real estate market. When the entire study area is taken as a whole, we actually see a positive correlation between sinkhole densities and housing densities, another result we might not instinctively expect. This phenomenon could be due to reporting bias, to the use of sinkholes as water features in newer developments, or to excessive stress placed on the karst by new development projects. The results of the analysis conducted here suggests that setbacks can be an effective regulatory tool to control development in karst terrains; however, it would be worthwhile to examine more closely why setback ordinances did not appear to have the anticipated effect on changes in residential density in sinkhole-prone areas throughout the 1990s, with specific attention paid to localized factors.

We get no such mixed results from our Pennsylvania case study. Those findings do not support the hypothesis that municipalities employing restrictions on development and construction in karstic areas suffer an economic disadvantage, relative to municipalities that do not employ such restrictions. It seems that there is no rational economic basis for planners and policymakers to consider the actions of neighboring towns and cities when contemplating the possible future implementation of karst regulations in their own jurisdictions.

This is interesting because it suggests that it should be feasible to implement karst regulations in areas that need them without worrying too much about unintended and undesirable impacts on the local economy. Even if densities are impacted, it doesn't seem that this impact takes the form we might expect based on the dictates of conventional economic thought. It seems probable that a wide range of other policies are likely to affect density more than karst regulations do. Ultimately, the results of these case studies can be used by proponents of regulation-based solutions to counter certain anti-regulation arguments, particularly those that are based on the threat of some potential, unknown (but almost invariably negative) future economic impact.

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Chapter 5
Karst Land Use Regulation in Rural Settings

Abstract The specific nature of the issues relating to regulation and land use are different in rural areas than in urbanized areas, and they often require taking a different approach in addressing those issues. This chapter examines questions of karst land use regulation in rural areas through a pair of case studies. The first case study describes attempts to develop a parcel of land containing Brooksville Ridge Cave in Hernando County, Florida, and helps to illuminate both the role and limitations of land use regulation in protecting unique karst features from the inevitable damage that a large-scale residential development would bring with it. The second case study examines the development and implementation of a protected area plan in Romania's rural Apuseni Natural Park, where park managers have faced significant obstacles in the implementation of an enforceable set of regulations that would protect the park's noteworthy karst resources.

Keywords Protected area management · Brooksville Ridge Cave · Romania · Rural · Economic development · Karst protection

Until this point, this book has mostly discussed the use of land use ordinances and regulations in managing the challenges inherent to urbanized populations existing on karst lands. But karst landscapes are also found in less developed, wilder areas; in many cases, these landscapes are in close proximity to valuable natural resources, and could suffer serious damage if those resources are exploited without regard for the karst. The specific nature of the issues relating to regulation and land use are different in rural areas than in urbanized areas, and they often require taking a different approach in addressing those issues.

This chapter examines questions of karst land use regulation in rural areas through a pair of case studies. The first case study describes attempts to develop a parcel of land containing Brooksville Ridge Cave in Hernando County, Florida, and helps to illuminate both the role and limitations of land use regulation in protecting unique karst features from the inevitable damage that a large-scale residential development would bring with it. The second case study examines the development and implementation of a protected area plan in Romania's rural Apuseni Natural

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Park, where park managers have faced significant obstacles in the implementation of an enforceable set of regulations that would protect the park's noteworthy karst resources.

The Brooksville Ridge Cave

Brooksville Ridge Cave was discovered in 2002 by a recreational caver in rural Hernando County, Florida. The cave, which has been described as containing unique formations and is considered to be significant by amateur and professional speleologists alike, is located on undeveloped property adjacent to a golf course. This property has been the subject of development efforts for years, as the golf course owners want to build a large residential subdivision there in order to maximize the economic return from the golf course. The presence of the cave on the property has complicated matters significantly over the last six years, and no construction on the property has yet begun. This case study will explore the effects of the state of Florida's cave protection laws and applicable Hernando County regulations on the efforts to protect the cave, and on those to develop the property.

The Nature Conservancy has made repeated attempts to purchase the site, but, being bound by appraisal values, they were unable to meet the property owner's high asking price. Over the ensuing years three major development corporations have courted the cave's owner and entered into negotiations to build on the site. All three have withdrawn from their contracts, citing concerns of building on the unpredictable karst terrain.

The Landscape of the Brooksville Ridge

The Brooksville Ridge Cave is located in rural Hernando County, Florida, outside the town of Brooksville. The land containing the cave is privately owned by World Woods, which has developed a well-regarded golf course on another part of the property. The cave is located very near the Withlacoochee State Forest, and is adjacent to some of the last remaining tree stands of the Annutteliga Hammock, which was once known for its tremendous rock outcrops and sinkholes; the Punch Bowl sinkhole is located here, and was considered a significant local feature in the 1930s (Velsor 2008).

The cave itself contains fragile speleothems that are sometimes densely concentrated, and while its decoration and formations have been described as unique, it is by no means the only cave in the vicinity. Most caves in the area have been vadose caves, without human-sized openings or entrance points. Historically, they could only be discovered via digging them out or after a sinkhole collapse creates a new entrance (Florea 2005).

The cave is part of an extensive conduit network found beneath the land surface, generally at shallow depths in the structurally weak Florida limestone. Ephemeral sinking streams that vanish into sinkholes are not uncommon sights in this landscape; all these sinkholes probably feed into the Brooksville Ridge Cave and the Floridan Aquifer before making their way to Chassahowitzka Spring, five miles to the west of the World Woods property. Generally, it is safe to assume that all the sinkholes in the area are likely recharge points for the spring (Florea 2005).

Indeed, all the attention paid to the intricate and extensive formations within the cave has led people to overlook the importance of the local watershed; one local environmental professional has described groundwater as suffering from "out of sight, out of mind syndrome" (Werner 2008). Even the low levels of urbanization in the area—characterized mainly by expansive residential lawns and meticulously maintained golf courses—have increased the nitrate load carried by the groundwater. And most of the available data suggests that the overall health of the aquifer surrounding Chassahowtizka has generally been declining since the 1970s (Velsor 2008; Werner 2008).

Despite the sensitivity of the landscape around Brooksville Ridge Cave, it may well be possible to develop the land while limiting the impact of that development on the local karst. This would probably require, at a minimum, a thorough assessment of the area's drainage basins, a partial set-aside of the property, and the implementation of techniques to keep stormwater runoff from draining into the caves. Stormwater control techniques could be as simple as basic avoidance, where runoff is directed away from the cave and other karst features, thus making it less likely that surface-level pollutants will contaminate the cave.

These precautions would almost certainly mean that the permissible housing density would be lower than that desired by the developer. But even then, any significant level of residential development brings with it the threat of aquifer drawdown, which could have serious consequences for the cave in general, and specifically for the biota within it. Without more hydrologic data from the area, it is nearly impossible to predict any specific impacts of development on Brooksville Ridge Cave (Velsor 2008; Werner 2008).

Efforts to Develop the Land and to Protect the Cave[1]

Brooksville Ridge Cave was discovered when local cavers noticed gusts of air emanating from a small crack in the ground; this is a telltale sign that a cave exists beyond that crack. The amount of air moving suggested the cave was a large one. The cave's discoverers immediately realized the cave's significance—the intricacy and size of many of the cave's decorations were extremely unusual, like bushes of 12-inch helictities (these rarely grow larger than four inches). These recreational cavers recruited like-minded friends to begin exploring the cave's significant lower section over the next several months, during which time the group located a series

[1] Much of the chronological information in this section is derived from a series of articles published in the St. Petersburg Times between June 2003 and October 2007.

of rooms with decoration that outshone anything else known in the state of Florida: translucent, pastel-colored speleothems; collections of hundreds of tiny rimstone dams; hundreds of faceted, carrot-like stalactites (Turner 2008).

It was during this initial exploration phase that one of the cave's discoverers contacted The Nature Conservancy and the Southwest Florida Water Management District with the intention of eventually getting the land into state hands. Initially, ownership of the cave itself was not clear, and there were no signs or markers delineating where state forest property ended and World Woods property began. Once it became clear that the cave was in fact located on World Woods property, The Nature Conservancy, which often negotiates land purchases on behalf of the state, attempts to initiate talks to purchase the property from World Woods. The company turned down the offer, describing it as too low. Four days later, however, World Woods reversed itself and suggested that it might be willing to part with the desired parcel. Negotiations, mostly focusing on the value of the land, were then conducted over the next six months.

At this point the company was not aware that there was a significant cave located on its property; by Nature Conservancy estimates, the cave and its associated drainage system may take up 25% of the entire parcel. The Nature Conservancy did not inform them of this fact, stating later that it was not their job to apprise property owners of the features on their own properties. It was during this period that the existence of the cave was first publicized, first in a publication of the National Speleological Society, and then later in the St. Petersburg Times. However, in both cases the exact location of the cave was kept secret, so even this announcement did not alert World Woods to the existence of a cave on the property they were hoping to develop.

At the same time, the cavers who had first discovered the cave (and who had since unilaterally assumed exploration and protection responsibilities for the cave) had begun surveying, photographing and collecting data from the cave in earnest. The cavers also installed a gate to restrict access to the cave, despite the fact that they were on private property and had no legal right to do so. Nearly a year after the deal between World Woods and The Nature Conservancy fell through, the company struck a deal with WCI to develop the property, a deal the cavers learned about once survey stakes began appearing on the property.

It was only then, in October of 2004 and nearly two full years after the cave's discovery, that The Nature Conservancy and the cave's discoverers revealed the cave's location to both World Woods and to the Hernando County Planning and Zoning Department. The information seems to have been kept secret not with the intention of deceiving World Woods, but as a way to prevent the cave's location from being entered into the public record, as would have been required under Florida public records law. A World Woods spokesperson described himself as furious that the company had not been informed of the cave's presence until that point.

A few months later, the county rejected WCI's attempts to amend the comprehensive plan. The company wanted the right to build 1680 homes on a parcel that had originally been permitted for 660 homes. County planners recommended the request be approved, based on the ability to provide the required infrastructure and utilities. Two weeks later, however, the county commission voted to reconsider their decision after a consultant working with WCI told the commission that the company was trying to preserve the land above the cave itself, and that the state may be able to purchase the land. This decision meant that WCI would not have to resubmit their proposal after making changes, which could have added months onto a process that can take up to a year when everything runs smoothly. The decision did not go unnoticed, and drew strong criticism from both local cavers and area media sources for giving WCI what amounted to preferential treatment; the St. Petersburg Times described it as "unprecedented" (February 16, 2005).

A month later, in February, the commission voted to approve WCI's request. However, the change also included language that addressed the cave system. The cave system must be mapped by a professional geologist before development will be permitted to begin, and WCI's choice to conduct this mapping would be subject to county approval. The cave system would then be made part of a preservation tract, which would eventually be managed by an organization with the resources and expertise to do it.

But the following month, while the revisions to the comprehensive plan were making their way through the state approval process, WCI unexpectedly announced they would not develop the property after all. A company vice-president cited the presence of Brooksville Ridge Cave, and the uncertainty associated with developing above it, as a significant factor in the decision.

Around the same time, local cave experts as well as out-of-state karst consultants were trying to secure a contract from World Woods to survey and explore the cave, and provide recommendations for future action based on data collected in those expeditions. The work was eventually performed by a Kentucky-based consultant, whose report was strongly criticized by some individuals with knowledge of the cave and karst systems in Hernando County. The report posits that the cave is actually quite small, at less than 3 acres, and is mostly bereft of formations (Gulley et al. 2005). World Woods then said that about 70% of the property will remain undeveloped (Coastal Engineering 2005); however, this figure includes land already occupied by golf courses, which is problematic because of the high potential for nitrate and pesticide contamination from golf course runoff.

Later in the year, Florida's Department of Community Affairs—the state-level agency with review authority over World Woods' request for changes to the comprehensive plan—recommended that each of the desired amendments be rejected. Concerns had to do with utility service, contamination hazards to Chassahowitzka Spring, traffic issues and completeness of the application (it was missing transportation-related data). The fact that the project included plans for over 1000 houses meant that it was subject to the requirements of a Development of Regional Impact (DRI). The next developer to become involved in the project proposed in early 2007 to split the development up into two separate projects of fewer than 999 units each, to be owned by two separate entities, as a way to avoid the requirements of the DRI process. This proposal also contained a recommendation to reseal the cave entrance. Cavers saw this as World Woods reneging on its agreement to protect the cave; a company spokesperson argued that placing the cave in its natural state was the best possible protection. By July of that same year, this developer had also withdrawn from the project.

The cave was finally gated by World Woods in late 2007; the gating was a direct response to a St. Petersburg Times article that described how easily vandals were able to enter the cave and damage some of the rarest and most intricate formations. As of this writing, no official plans have been announced to develop the property, but rumors to that effect have cropped up from time to time in the local caving community. It should be emphasized that these rumors are, as of this writing, unsubstantiated.

How Hernando County's Groundwater Resource Protection Ordinance Governs Land Use

As mentioned earlier in this book, the state of Florida does have a cave protection law in place. However, it is often described by cave enthusiasts as too weak to provide any actual protection, and therefore likely has little impact on the state's caves.

Like most state cave protection acts, the primary focus of the Florida statute is vandalism. The act makes it unlawful to damage speleothems or other formations or otherwise deface a cave's interior; there is also a related section prohibiting the sale or transporting for sale of any speleothems that have been unlawfully removed from a Florida cave. The statute also makes it illegal to harm or kill cave biota. And while these provisions are certainly critical to any attempts to preserve caves in their natural states, they are inadequate to address questions of protecting caves from external influences, like pollution generated by industrial or agricultural land uses, for example.

Unfortunately, the other provisions in the law do not rectify this situation. Like most state-level cave laws, Florida's cave protection law does provide some protection against contamination from human activities, but the wording of the law is such that it only prohibits dumping directly into the cave, or storing hazardous material inside a cave. It provides no protection to caves from external actions or occurrences that directly result in the pollution or contamination of a cave, like an accidental chemical spill occurring fifty feet from a cave opening.

The statute specifies that any violation of this law constitutes a first degree misdemeanor, which is punishable by a $1000 fine. Considering the difficulty in enforcing this law, combined with the prices some speleothems are able to command, this penalty hardly seems adequate to dissuade much in the way of cave degradation; certainly it provides no protection whatsoever from degradation resulting from inappropriate land uses in the vicinity of caves.

In a less karst-specific context, chapter 187 of the state comprehensive plan requires local governments to use appropriate regulatory means to protect local aquifers from contamination. In a heavily karstified area like Florida, this essentially amounts to a requirement to implement karst protection regulations in the appropriate situations. Similarly, Hernando County's comprehensive plan contains a list of objectives relating to the protection and preservation of the integrity of the local aquifer recharge system, as well as policy language on the identification and preservation of environmentally sensitive lands as well as development of land above cave systems. These policy goals are addressed by Hernando County ordinance 94-8, which is also known as the groundwater resource protection ordinance and is intended to "protect and maintain the quality of groundwater in Hernando County by providing criteria for land uses and the siting of facilities which use, handle, produce, store or dispose of Regulated Substances; and by providing protection to vulnerable features which discharge directly to the Floridan aquifer."

According to the ordinance, the whole of Hernando County is defined a groundwater resource protection area, based on the physical characteristics of the landscape and the aquifer. The ordinance also defines designated wellhead protection areas (WHPAs), the borders of which are based on time of groundwater-travel contours around community public water supply locations. These differ from Special Protection Areas (SPAs), which are placed around landforms that have the potential to discharge directly into the aquifer. This would naturally include karst formations, and indeed the ordinance specifically mentions both sinkholes and caves. These SPAs are plotted at a distance of 500 ft from the edge of the feature in question.

The practical effect of both WHPAs and SPAs are to restrict land use activities in these particularly sensitive locations. There are actually two WHPA designations defined by the ordinance: WHPA-1, which either restricts or prohibits dumping, certain agriculture-related activities, the placement of new residential subdivisions with a density greater than one unit per acre that lack a central sanitary sewer facility and wastewater treatment plant outside the WHPA, and the construction of golf courses, unless they do not use pesticides or fertilizers that can drain into the aquifer; and WHPA-2, which contains no restrictions for subdivisions or golf courses. The SPA zones feature restrictions that are very similar to those in force in a WHPA-1 zone. The cave itself is not in a WHPA zone, but as other development projects unfold in the general vicinity, this could change as new community public water supply locations are added to meet a growing population; ironically, this means that new development nearby could actually help save the cave, or at least contribute to improved conditions inside.

The ordinance does contain enforcement provisions, a crucial component for any functioning ordinance. Under the ordinance, the county can compel landowners to submit to an inspection and examination of their lands. People who violate the ordinance are subject to assessment for cleanup costs, a fine of $500 and/or jail time of up to 60 days. The ordinance also includes an appeals process, through which landowners can argue that their property should not be subject to the restrictions of a WHPA or SPA.

Planners in Hernando County also attempted to more directly influence the relationship between the prospective development and the BRC system through the project scope document. The second draft of the project scope agreement between the county and the company (completed in 2005) included new requirements for groundwater protection and data collection. Buffer areas were required for karst features on the property, as was the development of a map that overlay the cave and its passages atop a topographical representation of the property. New data would be collected via a series of test drillings, to be spaced at a distance of 30 ft in selected locations on the property; a consultant would then provide a full hydrogeologic evaluation on and around the project site. The developer would also be responsible for identifying and describing all subsurface features and explaining how they were hydrogeologically tied to the cave. The data collected in this way was supposed to form the basis of their recommendations.

Assessment

It seems clear that in the case of Brooksville Ridge Cave, state-level cave protection laws have done little to effectively preserve the resource. In the six years since the cave's initial discovery, it has undergone extensive degradation, including but not limited to speleothem removal. The most obvious factor contributing to this is a lack of enforcement, regardless of whether it is due to a lack of enforcement resources or is the result of a point of view that places cave protection somewhat lower on the list of priorities.

Hernando County's groundwater protection ordinance is a reasonable effort to fill any gaps in protection left by the state statute. As of this writing, the property surrounding the cave remains undeveloped. Three potential development partners have withdrawn from the project, and in at least one case the presence of the cave was a significant factor in that decision. It seems unlikely that this would be the case if this ordinance was not in place; even though the penalties for violating the county ordinance are not severe, the ordinance gave the county's planning department several legal justifications for either preventing or delaying the development of the land surrounding Brooksville Ridge Cave.

Hernando County's experience demonstrates that regulations alone are not enough; those with an interest in developing on karst lands will seek to circumvent rules when possible. The reason Hernando County's ordinance is effective may also lie beyond the actual text of the law. In Hernando County, all subdivision and commercial development reviews must go through the county's environmental office, where staffers have a high level of knowledge of applicable laws and regulations, as well as the desire and ability to enforce them. This is particularly critical in the face of developer efforts to seek out loopholes in the process and to attempt to circumvent the regulation. There may be no better example of this behavior than the successful effort of World Woods to get the county commission to reconsider its proposal; the company completely ignored established appeals processes and directly lobbied the commission for a second chance, a move that has been described by local observers as "unprecedented." This incident suggests very strongly that, regardless of the wording of any law or regulation, those in charge of enforcing the rules must do so; otherwise the rules are pointless. A dedicated, professional staff is needed to ensure the regulations are upheld.

Another challenge is that all development approvals in Hernando County are supposed to be contingent on scientific information supplied by the developer, certifying that no adverse impact will occur as a result of the development. One issue that immediately arises is that the phrase “adverse impact” is difficult to define objectively, in no small part because of the difficulty in obtaining comprehensive and accurate scientific data. In Hernando County, the responsibility for hiring and paying consultants to assess caves generally falls to the developer. This situation may result (either consciously or not) in oversensitivity on the part of the consultant to the needs of the developer. This is a direct result of tight budgets at the county government level, which are common throughout the country. Regardless of the cause, if the burden of cave assessment is placed on the developer, the developer will have a natural incentive to make that burden as light as possible. Counties should make more of an effort to find money in the budget for this type of environmental assessment whenever possible, which admittedly will not be as often as one might like.

Certainly, in this particular incident, the issue of obtaining comprehensive and accurate data was complicated by the “dueling experts” phenomenon; county officials heard conflicting opinions on the size, sensitivity and significance of the cave from at least three consultants or karst experts. The official consulting report to World Woods was criticized as being incomplete and inaccurate, and the depth of the consultant’s understanding of Florida karst (as opposed to Kentucky caves) was called into question (Florea, 2005). Generally, the members of a county commission or other similar governing body will lack the detailed scientific knowledge to evaluate the claims of experts offering opposing opinions. In this particular case, some individuals with first-hand knowledge of the history of BRC say that the political dynamics of local caver culture contributed to these disagreements. There is, of course, no guarantee that any two consultants will come to basically identical conclusions even when in-group politics are not a factor; however, it can be safely said that such an influence will rarely make that outcome more probable. It seems likely here that the disagreements among experts made it easier for World Woods to put forth a credible argument that development of the property should be permitted, and more difficult for the county to insist on a higher level of protection for the cave.

The Apuseni Natural Park (Romania) and the Development of a Protected Area Strategy

The Brooksville Ridge Cave case study described how land use regulations can be applied to karst protection in rural locations. In that case, the main technique used was not especially different from techniques used in more urbanized areas throughout the country. This was feasible because the parcel at issue is relatively small. However, in some cases, much larger tracts of open, rural land may require a level of protection and management that cannot be achieved through the use of regulatory techniques intended for municipal environments. Because of that, governments will often establish protected areas in these locations, with the intent of protecting the karst from certain human activities. Protected areas are areas in which land use restrictions are implemented with the specific purpose of preserving the integrity of the natural resources of an area. In some cases, this protection extends to resources not directly related to karst, including forests and surface waters, since applying protections to resource bases like these can often have beneficial spillover effects for local karst systems.

It may seem that the protected area management style of karst protection is a completely different animal from the techniques examined so far in this book. So why examine it here at all? Because, despite the obvious differences in environment, there are enough similarities in the implementation process to merit an examination of the protected area style. Protected area managers in karst terrains use a common toolbox that contains a finite number of regulatory techniques. Just like their municipal counterparts, managers of protected areas must identify the appropriate tools for their specific location, and often must navigate tricky political hurdles in order to implement them at all. In particular, there are often near-intractable challenges involved in simply getting the various stakeholders on board with the plan in the first place. It is very easy for this part of the process to change the regulation in such a way as to render it significantly less effective than intended. In this way, protected area management is similar to municipal-level regulation of land use on karst.

The Apuseni Natural Park

The Apuseni Natural Park is a near-ideal environment for studying the process of initiating and implementing a protected-area style karst protection regime. For one thing, the park is a large, non-urbanized area where the interaction between humans and the underlying karst system has the potential to adversely affect both the karst itself and the local human population. For another, the park is at a pivotal stage in its life-cycle, in that it is relatively well established as a nature park, but has only recently developed any sort of official management plan that attempts to address the issues of human-karst interaction. Finally, because Romania is one of Europe's poorer countries[2] (World Bank Development Indicators 2006), any karst management approaches implemented by the management plan will have to work within strict budgetary and funding constraints; these approaches would therefore be more likely to be transferable to other low-wealth countries with significant karst resources.

The Apuseni Mountains are part of the larger Carpathian mountain range, and are located in the western part of the country, where much of Romania's karst can be found. This is the location of the Apuseni Natural Park, which contains approximately 80% of the karstic rocks of the Bihor-Vladeasa range. Overall, Romania is

[2] According to the 2006 edition of the World Bank Development Indicators, Romania is categorized as a "lower middle income" country. Seven other European countries—Albania, Belarus, Bosnia and Herzegovina, Bulgaria, Macedonia FYR, Serbia and Montenegro, and Ukraine—also share this designation. Most of the balance of Eastern Europe can be found in the "upper middle income" category, with all of Western Europe categorized as "upper income." Moldova is the only European country found in the "low income" category.

not a highly karstic country. Less than 2% of Romania's land area is underlain by carbonate bedrock and while 13% of the country's overall water supply comes from groundwater, only 2% of that comes from karst lands. These figures are among the lowest in Europe (Zwahlen 2003). However, much of the karst that can be found in Romania exists in and around the Apuseni Natural Park, which contains dozens of significant caves (including the Scarisoara Ice Cave and one of the deepest caves in Romania) and countless sinkholes, many of which are used as makeshift trash dumps (Mos 2007). The idea of creating a nature park in the Apuseni region was first raised in the 1940s by noted Romanian biologist Emil Racovita, as a way to protect the area's karst landforms and features. The park was officially created in 2003, with the understanding that a park management plan would follow (a draft was completed in 2006). This plan would be designed to manage the natural park and the natural resources inside it, and would have to balance the twin objectives of protecting the natural resources of the park while simultaneously enabling the park's population to develop economically.

The establishment of the park itself is rooted in the legal authority provided by a government order issued in 1990. The park management plan draws upon Romanian federal law (Law No. 462/2001) as the legal basis of its authority, with various other federal laws, orders and government decisions providing a legal framework for day-to-day operations of the park and the implementation of the plan. The plan includes a significant cave management component, which will be explored in detail later in this chapter.

Ordinarily, protecting karst landforms within a natural park would be a relatively simple matter of restricting access and usage of karstified lands. However, in the case of the Apuseni park, the issues are a bit more complex. The reason has to do with the area's human population and its impacts on the park's karst. As late as the 19th century, Apuseni peasants were commonly engaged in low- or no-impact industries like handicrafts and trade instead of timbering. But the beginning of the railway age at about that same time helped change the nature of the local economy, simultaneously contributing to a general overdevelopment of the area and to biodiversity changes (new transportation technology made it easier to import alien species as well as export timber products). This overdevelopment had historical precedent; deforestation has been a recurring ecological theme in the region, dating back to occupation by the Romans (Turnock 2002).

Today, the area of the Apuseni Natural Park has a total population of approximately 10,000 people, dispersed among the park's 75,786 hectares. Certainly this is not a high population density in an absolute sense. However, Western protected areas usually—though there are exceptions—do not contain populations of that size, which adds a complicating factor to any analysis of the management plan in place at Apuseni. Despite the size of the overall population, the individual settlements themselves tend to be quite small—for example, Scarisoara, located at the southern end of the park, has only about 600 residents and is characterized by scattered clusters of between two and eight houses. Small-scale agriculture is widely practiced; most houses are adjacent to at least a small agricultural plot, and the landscape is dotted with sinkholes that have been converted to agricultural use.

While electricity is available in some areas of the park, access to it is not universal, and not all homes that have access are actually connected to power lines. Groundwater quality in some areas of the park is poor; however, these problems are quite localized, and are not widespread enough to prevent park residents from drinking directly from local streams. Some communities have begun using waters from the local karst system as the source waters for new, modern water supply systems, which are being developed and implemented as a means of modernizing the mountain lifestyle and of attracting tourism opportunities. Much of the park lacks direct access to sewage services; in some areas, residents just dump their wastes wherever they can. This is a tricky problem to solve, as the dispersed population makes it difficult to cost-effectively implement any kind of sewage infrastructure. Biological pollution of the groundwater has occurred as a result of certain actions on the part of tourists and local residents—including inappropriate dumping of wastes—but it is not considered a major problem yet. In some areas, fecal contamination is significant enough to render the water non-potable. Chemical pollution has not yet been encountered, perhaps because there are no potential sources of such contamination within the park (Mos 2007; personal observation 2006). Still, the current version of the park's management plan notes that "the majority of water sources in ANP are affected by pollution; some of them are even not potable" (Apuseni Natural Park 2006).

Roads in the Apuseni Natural Park tend to be very rough, with some being little more than trails. The entire park has only a single paved road; for most of the park, vehicle access is only possible via potholed dirt roads. Some park personnel and local speleologists argue that the lack of paved roads actually works to the park's advantage by limiting access for logging trucks and tourists, which in turn makes it easier to preserve the park landscape. Preventing excessive logging and timbering is seen by park management personnel as paramount in efforts to preserve the natural state of the park, as deforestation has well-documented negative impacts on karst systems and landforms (Apuseni Natural Park 2006; personal observation 2006; Mos 2007).

Protecting a karst landscape such as this one would likely be very difficult, if not impossible, using the municipal-level regulatory tools commonly found throughout the karstic regions of the United States. Instead, park managers have decided to take the protected area approach. As the next section demonstrates, this approach is often used in isolated, less economically developed landscapes; however, it is not without its drawbacks.

The Protected Area Approach: An Overview

A protected area is "an area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means" (World Conservation Union 2000). Six different types of protected areas are identified by the World Conservation Union (IUCN): the strict nature reserve; the natural park; the natural monument; a habitat/species management area; protected landscapes and seascapes; and managed resource protected areas. All of these area types incorporate different levels of protection, from preserving nature in an undisturbed state to protecting the sustainability of an area's natural resources in order to ensure that future use of the resource is possible.

Within protected areas, some sort of federal authority is generally cited by as justification for the implementation of karst protection policies. For example, the Grand Canyon Recreational Area cites the Federal Cave Protection Act as well as National Park Service Management Policies as the source of its authority to regulate the park. A set of 1998 revisions to these NPS policies explicitly state that "local and regional hydrological systems resulting from karst processes can be directly influenced by surface and sub-surface land use practices . . . If existing or proposed developments such as buildings, roadways and other infrastructure do or will significantly alter or adversely impact karst processes, these impacts will be mitigated. If mitigation is not possible, alternatives outside of the karstic area will be sought" (U.S. Park Service 1998). These sources are also cited by management plans published for Carlsbad Cavern in New Mexico and Sequoia and Kings Park in California and Nevada.

The IUCN has published guidelines for cave and karst protection, which are intended to boost awareness of karst-related issues within the IUCN and other associated agencies. The emphasis here is on national parks and protected areas, rather than urbanized environments. The guidelines acknowledge that karst systems routinely interact with wider ecological and environmental systems, and that such interaction can easily lead to damage or contamination even when stringent protection programs are in place. In essence, the guidelines argue, the establishment of protected areas is not enough: rather than limiting protection to only those landforms located within park boundaries, entire karst systems must be protected.

> Where a karst area as a whole, or any part of such an area, is under consideration, the protection strategy chosen should provide for protection of the total catchment wherever possible. Where this is not practicable, there should at least be an extensive buffer surrounding the key features to be protected. (World Conservation Union 2005, p. 15)

Accomplishing this will require a holistic approach toward managing water and air quality and movement between the surface and karst environments. In some countries where karst protection is a pressing issue, the expertise required to do so is not present, and must be brought in from abroad. As more and more management agencies implement karst-specific management policies, the importance of international information exchanges has become magnified. Indeed, such exchanges become all the more important in cases where effective, well-recognized policies and practices are followed but not formally documented.

How Protected Area Plans Work to Protect Karst Resources

Like municipal-level karst land use regulations, protected area plans tend to draw from a short list of regulatory tools and techniques as ways to achieve policy goals. In a karst context, the most common regulatory techniques include cave classification schemes, natural resource management (like forest stands, for example), working with nearby landowners and stakeholders not directly subject to park authority, and visitor and local resident education programs.

In cave classification schemes, public access is usually limited to certain classes of caves, with others set aside for scientific purposes or closed due to safety concerns. In practice, cave classification schemes wary widely in complexity: Kentucky's Mammoth Cave National Park employs a detailed, well-developed system, using six different classes (or "zones") to differentiate caves on the basis of scientific value, fragility and accessibility, while in Australia, both the Mole Creek Karst National Park and Conservation Area and Naracoorte Caves National Park plans use a three-zone classification system (public caves, special access caves, and wild or unclassified caves). In many cases, each classification has further subclassifications, and at Naracoorte, different parts of the same cave may have different classifications. Mole Creek also caps the total number of visits per year for each cave; once that cap is reached, the cave is closed.

Working with nearby landowners to protect the karst inside protected areas is often unavoidable, simply because of the extensive and expansive nature of so many karst systems. In any park, the dependence of protected karst on water flowing in from areas not subject to protected area plans has the potential to render any management plan ineffective from the start. In the early 1970s, Mammoth Cave management approached both the owners of the agricultural lands that surrounded the park and local land use planners in an effort to block changes in land use that might lead to degradation of the cave resources. Mole Creek has a similar problem, but because the park lands are not all contiguous, the situation there is somewhat more challenging than in most other parks. The park's disjointed nature simultaneously makes it extremely difficult for it to address questions of logging, agriculture, waste disposal, and land clearance in the vicinity of the park's karst features. The plan proposes a joint karst management program with the local forestry service, and a policy of collaboration and liaison with park neighbors and other users of the nearby Mill Creek-Kansas Creek catchment area. One objective of the management plan is growing support for the park and its overall goals within the community via soliciting stakeholder input, improving communication between stakeholders and park officials, and involving local caving clubs in appropriate aspects of park management.

Yorkshire Dales National Park: An Example of Another Approach to Protected Area Management

Not all protected areas in karst terrains rely on cave classification schemes to preserve their resources. Instead, some choose to take a more open-ended approach to protection, and as a result, they develop significantly different management plans. Located in the Pennines, in England, the Yorkshire Dales National Park has some of the best examples of limestone karst landscapes in all of Britain; highlights include several major cave systems and some textbook examples of pavement karsts. The park also contains significant limestone-based habitats, including upland pastures, limestone pavements, and wooded areas, that merit protection. Like Apuseni, Yorkshire Dales is not exclusively a karst park; park management hopes to preserve not only geologically significant features, but also the biodiversity found in the park and the cultural characteristics of the people living there.

Also like Apuseni, people live in the Yorkshire Dales National Park—the park has nearly 20,000 residents today—and have in fact lived in the area for thousands of years, dating back to the Paleolithic era. Traditionally the local economy was based on agricultural and pastoral activities, like livestock farming and cheesemaking. Agriculture is still important there today, but its viability as a sustainable commercial enterprise is threatened by larger forces beyond the park's control.

Demand for recreational services in the park has been growing for some time. Demand for vacation homes in the area is also growing, which has the effect of pushing housing costs beyond the range of affordability for the generally lower-wage inhabitants of the park. The park also has problems stemming from the increasing amounts of waste generated by individuals and business enterprises, despite the establishment of recycling programs. What landfill sites do exist in the park are characterized by limited future capacity, making waste reduction a priority.

The park's management plan is markedly different from those in place in parks like Mammoth Cave, Naracoorte Caves, Mole Creek or Apuseni, in that there are no explicit karst or cave management protocols laid out within it. The overarching goal of the park, like all national parks in Britain, is to protect and conserve the natural beauty, wildlife and cultural heritage of the park area, as well as to contribute to the economic and social well being of any communities located within the park. The Yorkshire Dales management plan sets out to accomplish this by broadly addressing seven components of the park: landscape, community and culture, access and recreation, understanding and enjoyment, nature conservation, historic environment, and economy and employment. It is emphasized that no element can really be addressed in isolation, due to the large number of connections between them all. However, the point that preserving the geology and geomorphology of the park is essential to properly understanding the overall landscape is made several times; one of the plan's objectives is to maintain all geologically important sites in "favourable" condition, though this term is never defined within the management plan itself. Recurring themes throughout the plan include sustainable development and sustainable land management (for example, farming using traditional methods is more expensive than using modern methods, but should be practiced nonetheless in order to preserve the park's unique cultural qualities) (Yorkshire Dales park management plan 2007).

As in Apuseni, park managers in Yorkshire Dales recognize the importance of maintaining the traditional lifestyle of park residents, since that is a key component of any plan to develop and grow economic activities centered around low-impact tourism. Indeed, the plan objective to develop a wide range of tourism initiatives driven by the park's image and its natural and cultural assets is supported by several of the other objectives laid out by the management plan. For example, the plan specifies that large-scale commercial agricultural operations are not permitted within the park, so as not to interfere with the more traditional agricultural activities practiced by park residents. More generally, the plan stipulates that environmentally sustainable economic activity should be actively promoted as good business practice and efficient in terms of resource consumption, with at least nine hectares of park land set aside for this type of economic development; further, the park's Sustainable Development Fund will be used to support future projects that are expected to bring desired economic, social and environmental benefits to park communities and their residents. Finally, some of the transportation-related goals of the plan include reducing the impacts of vehicle traffic within the park, in particular in the villages, and better integration of community transport services.

Successful implementation of the plan will require cooperation from external entities that have interests within the park's borders. In order to accomplish the goals of the plan, park management must develop working partnerships with the private entities that control fully 95% of the park's land. However, the specific nature of these partnerships is not spelled out within the plan itself, presumably to allow management to retain some flexibility.

The Yorkshire Dales National Park Management Plan takes a much different approach toward landscape and cultural protection than most protected area plans in karst areas. The management plan is not detailed, and instead seems to offer broad latitude to managers of how the plan's objectives should be accomplished. It is worth noting a second time that there is no section on cave or karst management within the plan, despite the fact that the park contains some of Britain's most important karst formations. For reasons that should become apparent later in this chapter, whether such an approach would be appropriate for the Apuseni Natural Park is questionable, despite the similarities between the parks.

Does the Protected Area Approach Actually Work?

Most of the Apuseni Natural Park is rural and undeveloped; it is, after all, a nature park. It is often difficult to get to nearby cities, and the rough local topography prevents the establishment of large-scale agriculture. The upshot of the geography of the park is that economic opportunities are limited for most of the people living there. Many area residents see the exploitation of the Apusenis' natural resources as their ticket to prosperity; however, the karstic nature of the area means that it would be particularly susceptible to the negative impacts of mining and forestry, which are two traditional natural resource-based economic activities in the region. Romania's natural park plan—which includes the Apuseni park—was designed with the intent of balancing conservation needs with access to woodlands and grazing. While the details are still being worked out, it seems that efforts to achieve this balance will focus on promoting the growth of certain low-impact industries (specifically, rural/eco-tourism and traditional crafts) and the de-emphasis of other higher-impact activities. In general, the land use implications of this approach include a greater priority for conservation of biodiversity resources, maintenance and possible expansion of woodlands, and a reduction in agricultural intensity (Turnock 2002); however, in Apuseni, agricultural intensity is already very low. Some experts feel there is reason to be optimistic about the prospects for the protection efforts underway in the Apuseni Natural Park, mainly due to the connection between a landscape's economic potential and the chance of success for conservation and protection efforts there: "Conservation attributes that occur in economically marginal hill and montane landscapes are relatively safe from degradation, whereas conservation attributes confined to lowland and coastal landscapes are under serious threat and are poorly protected" (Jepson et al. 2002).

However, others argue that the entire protected-area approach is problematic: "Considerable controversy surrounds protected area theory—which illustrates a positive and worthwhile concept—and practice, where little contextual evidence proves that protected areas are effective" (Urich et al. 2001). There is little argument that the effectiveness of protected-area and conservation legislation fluctuates widely from region to region. Approximately 12% of the world's karst landscape enjoys protection via designation as a protected area of some form; however, this amount is not distributed evenly. For example, approximately 18% of Central American karst lands are covered by protected area legislation, but as much as 86% of Belize's karst enjoys such protection. Specific levels of protection vary from country to country, which is often a reflection of population, economic and political conditions. Even when karst protection is available, conditions within the federal government have a noticeable impact on whether or not the protection is actually meaningful: does the federal government have the capacity, in terms of budget, manpower, and central authority, to plan and enforce large-scale natural resource management programs? Are attitudes toward conservation favorable or unfavorable? Asking these and similar questions may help gauge the potential for success of a protected area program before it begins (Day and Urich 2000; Urich et al. 2001; Kueny and Day 2002; Day 1996).

While the trend in karst protection policy is toward global and national protected areas, the act of establishing protected areas is almost always a local affair, with effects and impacts borne primarily by local residents. A case in point is the establishment of a protected area in the Chocolate Hills region of the Philippines—home to one of the world's best-known kegelkarst environments—which has led to conflicts between the federal government and local populations. In general, one problem with these kinds of conservation issues is that management rights and responsibilities can rest with either the central government or the local people. Government intrusion into land use practices and regulations often extends beyond the boundaries of the protected area itself. More ominous is the fact that, in the past, protected area creation has led to forced relocation of indigenous populations, impoverishment, and the collapse of traditional resource management systems. Other issues that must be addressed before protected areas in the Philippines can become a standard fixture of natural development planning include improving relations between protected area managers and local communities, improving protected area management practices; increasing international involvement and cooperation, and making these areas a standard and accepted part of society via education, training and research (Urich et al. 2001).

Criticisms of the approach notwithstanding, administrators at the Apuseni Natural Park in Romania have pressed ahead with developing a park management plan that is heavily rooted in the protected area approach. With Romania's recent admission to the European Union, the next several years promise to be a time of significant change for the entire country, as it attempts to transition from a struggling economy with strong structural ties to the old Communist system to a country that is, in terms of economics and governance, a peer of western European nations. To that end, the management plan for Apuseni Natural Park should be examined in a more western context, compared to existing plans from karstic areas in western nations.

The Management Plan for Apuseni Natural Park

In the summer of 2006, managers at Apuseni Natural Park published a draft management plan that outlines strategy and tactics for implementing a protected area approach to park land management. While the plan does include a set of karst-related components that, on paper, appears to be adequate, the main goal of the park itself is to manage the forest resources it contains. The karst protection aspects of the plan work by dividing the park into various "management zones," with each zone having a different level of acceptable access and use. Zone 1—the Scientific Reserve zone—is the most restrictive, with the only permissible human impact coming from scientific observation and monitoring activities. No other activities are allowed. Much of the significant karst lands in the park are classified as Zone 2 Special Conservation Zones. All activities permitted in Zone 1 areas are also permitted in Zone 2 areas. Other Zone 2-acceptable activities include controlled tourism, mostly limited to the use of visitor trails; pasturing with domestic animals under certain controlled conditions; and vehicular access. Specifically forbidden activities include anything that involves the construction of permanent buildings, other than those necessary for the administration of the park, and mass tourism; there is also a sweeping catch-all clause that says any activities not specifically approved for the zone are forbidden.

However, not all the karst areas in the park are contained in areas labeled as zone 1 or 2. This is apparent from a walk through the park itself, because there are people living adjacent to dolines in the vicinity of Scarisoara. These lands and others like them are most likely contained in Zone 3, the landscape protection zone, or zone 4, the socioeconomic development zone. Zone 3 contains lands reserved for traditional land uses, like forestry, pasturing, or temporary dwellings, and in which visitor access is encouraged. Zone 4 includes building areas of the communities spread across the park's territory, and more types of land use are permitted here (though construction and development is restricted in the vicinity of the Padis tourist zone, due to the sensitivity of the surrounding area). There are, however, still restrictions on the development of new residential and industrial buildings that go beyond the capacity of the local ecosystem to accommodate them, or that are inconsistent with park management objectives.

Beyond this large-scale zoning system, the Apuseni plan contains a cave classification system similar to those discussed earlier in this chapter. In the Apuseni system, there are four categories of caves, ranging from Class A to Class D. Class A caves are those with "exceptional value," and all activities other than scientific research and monitoring are prohibited. Newly discovered caves are automatically classified as Class A caves until further study permits a more appropriate reclassification. Class B and C caves are also protected, due to national or local importance, respectively; organized tourism or explorations are permitted in both classes with park approval. Class D caves are described as those that lack the specific qualifications to be placed in any of the other three categories.

Park management plans like this one are often difficult to implement because of conflicts with or between stakeholders. Here, those stakeholders encompass more than those individuals wishing to use or preserve the landscape. The park itself is actually split between three of Romania's counties, and there are 21 villages or communes that are stakeholders in the park; perhaps 15 of these are directly involved with park business, with the others simply owning property within the park. This adds an extra layer of administrative stakeholders that must be navigated, making the plan development process all the more difficult.

Threats and Solutions

The karst within the Apuseni Natural Park faces threats from several different sources; however, the plan itself concludes that the state of conservation of the park's karst is "at a rather satisfying level." This is attributed directly to the remote locations and lack of convenient access routes for a large number of the park's caves (Apuseni Natural Park 2006). Still, any future alterations to the park's physical and human landscape could result in a dramatic change in that assessment.

As discussed earlier, sinkholes in agricultural areas often lead to nitrate contamination of local groundwater supplies. However, in the Apuseni Natural Park, agriculture within sinkholes is not actually a significant threat to the local karst aquifer, despite the fact that the general lack of arable land makes the interiors of dolines and other karstic depressions more attractive for agricultural activities like growing potatoes. That is due in part to the fact that the agriculture here is very small-scale, mostly subsistence-level; generally, the agriculture practiced in the park was often intended to supplement the food supply brought in via trade with lowland farmers, who needed timber from the Apuseni forests. Additionally, chemical fertilizers are generally not used because they are too expensive for most park residents (Mos 2007). That said, in Section 3.2.1.2 of the plan, farming is nonetheless identified as one of the major contributing factors to the area's degraded aquifer. In addition to threats from fertilizers, intensive grazing can have an indirect negative impact on the karst aquifer by removing the vegetation that acts as natural filtering mechanisms for surface water prior to entering the karst system (Apuseni Natural Park 2006). This is a perfect illustration of the potential conflict between different objectives of the management plan (in this case, preservation of traditional ways of life vs. protection of the karst and groundwater resources) discussed earlier.

Illegal logging, on the other hand, is indisputably a major problem within the park. Large companies conduct timbering operations within the park and profit from the exploitation of the park's natural resources; however, because the logging takes place in a national forest, park residents do not control the timber resources, and little if any of this money ever makes its way into their pockets. Some park residents are unable to resist the profitable nature of forestry and continue to make their living from the trees, without official supervision or approval. Even so, these small-scale timbering operations do not pose the threat to the forest resource that is posed by larger corporations. Timbering issues in general have become a focal point for a bureaucratic turf war within the Apuseni Natural Park. There is a conflict between the park administration and the national forestry service, which now supervises the park administration. The park service sees its role as preserving the landscape, including the forest; the forestry service sees its role as encouraging and managing the use of the forest resources—in other words, to promote logging and timbering within the park (Mos 2007; Persoiu 2007).

The development of summer homes also threatens the park's karst systems. Illegal construction was once common in the area near the Cabana Padis, located toward the center of the park. While the newer cabins and seasonal homes under construction there in the summer of 2006 were being built legally, there were several others nearby for which no permits or approval papers were ever issued. Since the park's lands have been inhabited for centuries, buildings and settlements long predated the legal establishment of the park. However, much of the construction that has taken place since then has been illegal, and the park ultimately has no recourse against illegal construction. At most, violators are fined a nominal amount, but are never actually required to remove any illegally built structures. Park rangers in Romania have very little power, which is a sharp contrast to other countries in the region like Poland; because the park lacks sufficient enforcement authority, the highly profitable nature of illegal development means that nature and ecological concerns within the park are often ignored (personal observation 2006; Mos 2007).

Nearly all the park's natural systems are threatened by the aggressive and unchecked development of tourist infrastructure (Mos 2007). This is not to say that park managers wish to prohibit development within the park, or envision such a prohibition as part of the park management plan. In fact, quite the opposite is true: they recognize that some development is necessary to provide an economic framework for the park's residents. The real question is one of how to accommodate economic growth while simultaneously preserving as much of the park's landscape as possible. For both social and ecological reasons, the most widely desired type of development is small-scale, sustainable rural tourism, which is often thought to be a potential gold mine for places like Apuseni. However, many southeastern European countries, including Romania, have also proved either unwilling or unable to invest in tourism development, or to secure outside investment for such ventures.

But other countries in the region have seen investments in tourism infrastructure pay off; national parks in Poland and Slovakia, for example, have experienced booming business (Buza et al. 2001; Hall 2004; Turnock 2002).

The draft management plan is clearly intended to position the Apuseni Natural Park for a transition to a major tourist attraction within the region, while still maintaining and protecting the park's natural environment. The plan's goals were determined with input from stakeholder workshops, as well as by the core team in charge of developing the plan. Stakeholders in the Apuseni Natural Park area include:

- Romanian national government agencies, like the Ministry for Environment and Water Management, the Ministry for Agriculture, Forests and Sustainable Development, the Ministry for European Integration, and Romsilva, the Romanian forestry administration;
- Administrators from the three county governments with land inside the park boundaries (the counties of Alba, Bihor and Cluj);
- Various control and regulatory agencies at the federal and county levels, including the forestry directorates, environmental protection agencies and building inspection agencies from each of the three counties;
- Various partner parks in Hungary and Italy;
- Non-governmental organizations (NGOs), including speleological clubs and societies, ornithological societies, bat protection organizations, and ecotourism organizations;
- Local land owners, including communes, churches, schools, and private owners, as well as owners of weekend homes within the park; and
- Various schools, universities, museums, and research institutions.

This list is not an all-inclusive list, but does provide a representative description of the largest stakeholders in the development of the park and the writing of the management plan. According to the draft management plan, these stakeholders had input in the writing of the plan in general, and in the setting of park goals in particular. These goals are summed up on page 86 of the draft management plan:

> Apuseni Natural Park will be: an internationally important area of mountain karst landscape, with well-conserved biodiversity, specific and quality tourism, sustainable use of resources, and an infrastructure designed for sustainable development; and with local communities that maintain their unique traditions and a good standard of life.

Specific objectives are wide-ranging, as the park contains resources other than karst and the plan itself is obligated to address these resources as well. However, objectives relating directly or indirectly to karst formations within the park include the following:

- Conservation of the park's karst, and protection of the karst from damage and pollution;
- Increasing scientific understanding of karst;
- Boosting visitor awareness of, and improving visitors' experience with, the park's karst;

- Protection and restoration of aquatic habitats within the park, as well as prevention and reduction of pollution of the park's surface water and groundwater;
- Promote ecotourism and "nature-oriented recreation," as long as those activities are compatible with and appropriate for the park's karst formations;
- Promote and protect the local traditional lifestyle and cultural heritage of the Apuseni Mountains;
- Promote the development of "sustainable economic activities."

There are potential internal conflicts here; in particular, protecting resources like karst formations and groundwater can very easily come into conflict with the objectives of protecting traditional lifestyles and promoting sustainable economic development. Of course, that is probably why the word "sustainable" is included in that particular objective, with the implication that any sustainable development would, almost by definition, be compatible with the resource-related objectives.

Growing Tourism and Protecting the Natural Environment: Are They Mutually Exclusive?

Establishing a thriving tourism sector faces a problem from the lack of infrastructure, especially water and roads. Nearly all roads in the park are unpaved forestry roads; some formerly paved roads within the Apuseni Natural Park have reverted to an unpaved condition due to a long-term absence of maintenance. Waste disposal is another segment of infrastructure that will have to be improved to support a strong push into the ecotourism sector. While there are trash-collecting sites for tourists using the four approved camping locations within the park, there are no actual trash removal services because the park claims removal is the responsibility of the towns, which generally lack the money needed to actually provide the service (Persoiu 2007; personal observation 2006). The success of any strategy with an emphasis on private farming and expanding tourism would depend on improvements to these public services. Transportation in particular is critical, since the very roads that are needed to bring tourists to these locations have proved to be especially difficult to maintain since the end of the Communist era. Provision of other services is made all the more difficult by the settlement pattern of dispersed, "hamlet-style" villages scattered across rugged terrain. Some of these hamlets are not accessible to vehicle traffic at all. Perhaps these problems of accessibility offer a partial explanation of why relatively few Apuseni farmers participate in the young agrotourism industry, even though many of them consider growth of the industry to be highly desirable (Abrudan and Turnock 1998).

If the park is to develop a thriving tourism industry, the park management plan will be the tool that provides the blueprint for it. The plan outlines specific acts that will be taken to achieve the twin goals of tourism development and environmental protection. First, the plan describes four broad objectives related to protecting and preserving the park's karst: conserving the "patrimony" of the karst, increasing scientific knowledge and understanding of karst, facilitating and improving visitor awareness of karst, and reducing damage and pollution to the park's karst features and landforms. Each objective is connected to a list of the specific management actions that will be taken to achieve these goals. Each of these management actions has a priority indicator of 1, 2 or 3, where 1 is the highest level of priority. An examination of these priority indicators can help illuminate what aspects of the plan are considered most important by park management and the other stakeholders. The "facilitating and improving visitor awareness" objective has five management actions with a priority of 1 (out of nine total actions); reducing damage and pollution has only one action (out of seven) with as high a priority. Likewise, the objective of increasing scientific knowledge has only one top-priority action, out of a total of five (Apuseni Natural Park 2006).

The top priority management action relating to reducing damage and pollution to the park's karst is an educational campaign to inform residents about the consequences of polluting and littering upon the karst system. Two other actions listed in this category are designed to "promote" changes in infrastructure or in park resident behavior (specifically, to promote the application of organic fertilizer, and to promote installation of rural wastewater collection and treatment systems, respectively); these are given a priority of 2. In the former case, this lower priority might be because the poverty of park residents makes organic fertilizer a choice often made from necessity; likewise, the lower priority for promotion of wastewater systems could reflect the awareness that the cost of installing such a system is very high and essentially out of reach. The one action likely to yield more immediate and visible results—clearing trash out of sinkholes—also has a priority of 2. Under the "facilitate and improve visitor awareness" category, the park administration seems intent on walking a fine line between increasing access to the park's karst, and simultaneously imposing better controls on that access. High priority management actions include improving visitor access via thematic, self-guiding karst trails and developing a more comprehensive agreement relating to access to karst sites within the park.

At this point, the park's infrastructure is likely inadequate to support a profitable ecotourism sector. The Romanian government has attempted to help shore up the area's infrastructure with an 8000 billion *lei* program that also attempts to grow the region's tourist trade by providing "seed money" investments for local handcrafts and other businesses likely to reinforce the industry. Government-sponsored grants and financing for the promotion of ecotourism and nature preservation are crucial for the success of the project, because most developers and investors are reluctant to invest their own money in what is admittedly a very risky venture at this stage. It is hoped that, as development continues, word will spread throughout Europe about the recreation opportunities available in the park, which will then lead to an increase in visitors and a justification of further investment in the park, perhaps even without the inducements of grants. Other proposals for boosting tourism in the area—not specifically tied to this federal grant program—include improving mountain activities and establishing a Large Animal Center that would make it easier to observe large animals in their natural environment. The park administration is also trying to promote and support the development of other sustainable economic opportunities for park residents. These include sustainable production of natural medicines using plants found in the park and sustainable use of forestry products in the production of handcrafts. These activities are already occurring in the park, but on very small scales; still, they do provide potential investors with an example of the types of non-tourism economic initiatives that are considered suitable by park management. Even with the scale of financial assistance offered by the government, however, agrotourism in the Apuseni Natural Park would find itself competing for dominance with mining for bauxite, copper and limestone—all traditional economic activities that hold very little appeal for the average pleasure traveler. On the other hand, there is also a strong conservation movement afoot in the region, with 35 environmental non-governmental organizations (ENGOs) active in the Apuseni Mountains as of 2001. This movement could potentially hamper attempts at any type of economic and industrial development, perhaps by seeking the implementation of regulatory tools like controls on grazing and woodcutting (Abrudan and Turnock 1998; Mos 2007; Turnock 2002; Buza et al. 2001).

Apuseni Park officials clearly believe that the promotion of ecotourism in the region is important. In fact, tourism and possible ways to promote it are discussed at length within the plan itself. The section of the plan addressing the managing of visitors, tourism and recreation is well developed and detailed, with significant attention devoted to the image of the park, promotion of the park as a tourist destination, and general public relations. The very first goal is to develop a separate visitor management plan; both this and the development of a visitor infrastructure are listed as top-priority items. Clearly, this section has received a good deal of thought, and reflects park management's emphasis on developing ecotourism as an economic base for the park. In addition to ecotourism, administrators have been willing to encourage any other activities that simultaneously carry a minimal impact on the landscape, while also providing maximum income to park residents. In any case, planners will have to take care to avoid the great paradox of rural tourism: the growth and development of a successful rural tourism industry may very easily destroy the features and qualities that made such tourism possible in the first place.

It is this very realization that has led to some resistance to the promotion of ecotourism as an engine of economic development for the people of the Apuseni Natural Park. Some cavers argue that there is an inherent contradiction in attempting to protect caves by introducing them to the tourist circuit and exposing them to larger numbers of visitors. Park management claims that any caves opened to the tourist circuit would still enjoy a significant amount of protection, since no lights or footpaths would be installed; speleologists counter that any promotion of caves for tourism will by definition lower the level of protection provided, due simply to the increased human contact (Persoiu 2007).

It is interesting to note that none of the management actions listed in the "Sustaining and Promoting Local Culture and Traditions" section are given top-priority billing. This, combined with what we see in the section on managing visitors, strongly suggests that developing the tourist trade is more important to park administrators, and could very easily crowd out the development and growth of small-scale traditional economic activities (Apuseni Natural Park 2006).

Authority and Attitudes

Earlier in this chapter, the role of enforcement capabilities and attitudes toward preservation in protected area establishment and management was discussed (see Day 1996; Jepson et al. 2002; Kueny and Day 2002). Judging from the plan itself, and from discussions with stakeholders, the Apuseni Natural Park may find itself in the same situation as countless other protected areas around the world: unable to actually provide protection to the park's natural resources, regardless of what the management plan says.

In a park with as large a population as Apuseni, winning over the residents is critical to the success of any management plan. The size of the park's population made it impossible to consult each individual resident when attempting to incorporate their priorities into the park management plan; additionally, the sheer number of stakeholders other than park residents makes it necessary to work with representatives of each stakeholder group (major stakeholders are listed earlier in this chapter). Representatives of each stakeholder group then come together to form a workgroup, which was selected by park management; indeed, the entire process of collecting input from stakeholders seems to have been strongly guided by the park administration (Mos 2007).

Park residents were initially hostile to the idea of a management plan. This was due to residents' misunderstandings of the intentions of the park's administration, most of which were related to restrictions on permissible activities and access to natural resources for park residents. These misunderstandings were apparently capitalized upon and encouraged by interest groups who opposed the development and implementation of a management plan. Ultimately, it took two full years of work to turn these hostile and reluctant attitudes around. Park administrators conducted workshops, informal meetings, and organized exchanges between other European natural parks in their efforts to convince the residents of Apuseni Natural Park of the benefits of implementing a management plan (Mos 2007).

However, even as the idea of preservation has gained acceptance, the concept of a tourism-based economy has been slower to gain approval from park residents. It has been suggested that the park residents find forestry easier, largely because the paperwork required for tourism can be challenging; additionally, forestry is still far more profitable. This is related to the general problem with enforcement and with bureaucratic issues; many park residents seem to be waiting for these things to change before moving to the tourism trade. Additionally, some villagers are simply not motivated to start businesses and become entrepreneurs, particularly in a new and exotic field like ecotourism. This can potentially be overcome by convincing one person to establish a tourism business and helping him succeed; his neighbors may then attempt to emulate his success.

While park administration seems to have been successful in their efforts to bring about more favorable attitudes toward preservation among park residents, other stakeholders have not been as receptive. In particular, RomSilva (the Romanian forest service) is more focused on exploitation than preservation of the park's forested lands and has resisted buying into the application of the protected area management concept to the Apuseni Natural Park. The draft management plan itself, however, aggressively promotes resource preservation rather than resource exploitation. The nature of RomSilva's official mission and the high potential economic value of timber products made from park trees suggest that the forestry service's institutional attitude toward preservation in the park will be difficult to change; for this reason, some park administrators are actively pursuing the possibility of severing the park's official (and subordinate) relationship with RomSilva. However, such an approach could be counterproductive, especially if the park management lacks RomSilva's access to the various levers of Romania's federal government. Romania's forests are an important natural resource; RomSilva's control over them (and, by extension, the revenue they would generate) is in and of itself a source of significant political power. It seems unlikely that, in the event of a separation, a newly independent park administration would have the political resources to prevent RomSilva from doing as they like in the park. For that reason, a more constructive engagement with RomSilva should be considered, though it seems that the forestry service has little enthusiasm for that approach (Mos 2006; Persoiu 2007).

Enforcement authority is also a significant obstacle to the success of the management plan. Some stakeholders have raised the issue of whether the plan can actually be put into practice and enforced. The lack of enforcement authority is a key problem from the standpoint of cave and resource protection. Even if the park administration tells people not to cut down the forest, the management plan and Romanian law do not provide the authority to actually prevent anyone from doing so. Certainly, the park management plan carries with it the imprimatur of the Romanian government. The establishment of the park itself is rooted in the legal authority provided by a government order issued in 1990. The park management plan draws upon Romanian federal law as the legal basis of its authority, with various other federal laws, orders and government decisions providing a legal framework for day-to-day operations of the park and the implementation of the plan. Unfortunately, without the ability to impose significant fines or other penalties, the park is not likely to have much success in preventing illegal timbering operations or illegal resort home construction within its boundaries (Apuseni Natural Park 2006; Persoiu 2007).

Another example of the difficulty faced by park administration can be found in a disagreement between park management and the Romanian speleological clubs that operated within the park. Traditionally, the discovery of a new cave in the park did not result in the cave becoming the private property of the discoverer. Instead they remained (with some exceptions) in the public domain, which meant that anyone could access them. Management of these caves fell to the caving clubs. Each club had its own "territory" within the park, and each club was responsible for the caves within its territory. Speleologists affiliated with one club could still enter caves in other clubs' territories; however, by convention they mapped only the caves within their clubs' territory. Currently, the Romanian Academy of Sciences grants permission to enter protected area caves. Previously, when the park was first established, the park administration wanted to take control of all caves; this naturally would have included handing over the keys. The speleological clubs disputed the legal right of the park to do this, based on a different interpretation of the relevant Romanian law.

The dispute was resolved by permitting the clubs to retain control over the keys, with the clubs agreeing to notify park management when they decide to enter a particular cave. The arrangement seems to be a workable one, but periodically the park administration suggests it might prefer to increase the level of control they are able to exert over the caves (Persoiu 2007).

How the Apuseni Experience Relates to Karst Regulations in Municipalities

Planners working in urban areas can take valuable lessons from the Apuseni Natural Park's experiences in writing and implementing a management plan, despite the very rural and undeveloped character of the park. For one thing, it can often be much more difficult than expected to achieve acceptance from stakeholders, especially in cases where they may have interests that conflict with each other, or with the idea of karst protection itself. In the case of Apuseni, one large group of stakeholders—park residents—have historically perceived it to be in their interests to allow exploitation of the park's natural resources, like timber and ore. This perspective, combined with the belief that a park management plan would place excessive restrictions on access and land use, led to two years' worth of opposition and hostility from park residents toward the very idea of a plan. And RomSilva, the Romanian forestry service, is a major stakeholder in the park because of the vast timber resources located there. However, protection of the karst system requires these resources to be carefully managed—remember, it was rapid deforestation that led to the destruction and loss of western Ireland's karst aquifer centuries ago—and the whole point of RomSilva's existence is to promote timber harvesting.

Attempting to satisfy multiple policy goals can also lead to major problems, particularly if those goals happen to come into conflict. In Apuseni, we have a situation where the goals of certain segments of the management plan—specifically, protection of the park's karst resources—conflict with the goals (better exploitation of the park's forestry resources) laid out elsewhere in the same document. Because of the mechanics of karst aquifers, it is very unlikely that both goals can be met—either the trees must remain largely in place, or the karst must suffer as the landscape is denuded. What seems most likely is that natural environment protection will suffer at the hands of economic development. Certainly we can already see an example of this in the fact that RomSilva does not abide by the spirit of the plan and continues to exploit the forest resources in a way that is not consistent with the protected area concept (according to Section 3.2.4.1 of the Apuseni draft management plan, forestry issues are addressed in separate Forestry Plans, which had yet to be revised at the time the draft was published). This activity is the result of two factors: the inherent conflict that exists between the plan's main goals and from a lack of enforcement authority over RomSilva, which in fact has authority over park management. These do not appear to be issues that can be resolved through future drafts of the park management plan; intervention at higher levels of government may be necessary (i.e., either separating the park service from RomSilva or more constructively engaging the forestry service; improving the park service's ability to enforce its own rules).

This last point—that enforcement authority is a critical component of any set of karst land use regulations—cannot be overemphasized. The existing literature repeatedly points out the importance of enforcement, and the experience of Apuseni's park service professionals bears it out; indeed, the importance of enforcement ability was also demonstrated in the Brooksville Ridge Cave case study earlier in this chapter. Unless karst regulations can be vigorously enforced, they will be ignored. This can actually be a worse situation than not implementing regulations in the first place, because the failure of the regulations to halt degradation of a karst system could then be used to dismiss the effectiveness of the regulatory approach altogether.

This chapter demonstrates that even across landscapes that are superficially similar (in this case, a pair of rural landscapes with noteworthy karst feature development and vulnerable groundwater supplies), there is no one-size-fits-all approach to implementing regulations that are simultaneously effective at protecting the karst and appropriate to the local natural and human environments. Factors that should influence the final form of any regulations include the amount of land that requires protection, the nature of the threat in question, and local culture, which certainly includes the political culture, the consideration of traditional occupations and economic activity, as well as a more general understanding of the population's historical relationship to the landscape. Because of the complex way in which human systems and karst systems interact with each other, any attempt at regulation that forgoes consideration of these—and perhaps other—factors is not likely to succeed.

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Chapter 6
Moving Toward a Framework for Karst Land Use Regulations

Abstract This chapter draws upon the conclusions and data generated in the previous five chapters to begin the construction of a framework of karst land use regulation. The framework is loosely based in perspective of system theory, in that the issues discussed and explored throughout the rest of the book all stem from the interaction of karst systems with human systems, like cities and economies. Relative influences of various factors on the entire regulatory process are examined; through that, the beginnings of a framework are generated. Factors that receive particular emphasis include enforcement authority, attitudes of planners toward karst regulations, regulatory actions taken by neighboring jurisdictions, and technical expertise. The framework itself accounts for inputs into the regulatory process, the effectiveness and restrictiveness of various forms of regulation, and what the outcomes of these regulations are likely to be. However, due to the highly complex nature of the political systems discussed in this book, a quantitative model is elusive. Instead, this framework is highly qualitative.

Keywords Human/karst interaction · Regulatory framework · System theory

In the preceding chapters, we have attempted to sort through a large amount of data and information on karst related land use policies and regulations in an effort to lay the foundation for the development of a framework we can use to understand how these policies work, and how external forces can influence the final form taken by those policies. This process has incorporated both quantitative and qualitative data and has focused in particular on three study areas and on the input of land use professionals from across the United States. Conclusions drawn from the analyses conducted in these chapters are wide-ranging; however, the most pertinent findings include the following:

- In the United States, local karst-related land use regulations are often similar, if not identical, to other regulations found elsewhere in the same state. This suggests that municipalities may be more concerned with implementing regulations that will withstand legal challenges within their own states than they are with developing regulations that are carefully suited to the specific physical nature of the karst system below.

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- There does not seem to be any relationship between levels of urbanization and regulatory methods used, or indeed between urbanization and the very existence of karst regulations or ordinances. Several large, highly urbanized areas on karst have nothing more than rudimentary karst protections on the books; in many cases there are no regulations whatsoever. Conversely, some rural municipalities have taken more proactive approaches to regulating development on karst terrains. However, it should be noted that the data do not support the presence of an inverse relationship between government sophistication and regulatory sophistication.
- Stormwater runoff ordinances are a very common way—indeed, perhaps the most common way—to regulate land use on karst terrains in the United States. Reasons for this seem to include the visibility of the problems the ordinances are intended to address as well as its near-universal application in non-karst contexts as well.
- Overlay zones can be found in rural settings as well as urban areas. This is surprising, as it seems reasonable to expect that issues of human-karst interaction in less-populated areas could be resolved with less intrusive regulatory tools than the overlay zone.
- Employing mandatory setbacks as a regulatory tool is a more common choice for municipalities with more extensive karst formations. Setback or "no-build" ordinances can be an effective way to limit or control structural density when applied to areas where sinkholes are prevalent.
- Planners' attitudes toward karst land use regulation seem to be related to whether or not such regulations are implemented in the first place. However, it should be noted that it is difficult to get a fix on the direction of causality here: is the lack of regulations a result of the planners' negative expectations of such regulations, or are those expectations and attitudes a result of the absence of such regulations?
- The expected results of karst regulation, particularly "secondary effects" like changes in population density or growth rates, often are not observed in municipalities where such regulations are implemented.
- Higher levels of input into the regulation process from non-elected, technical professionals (for example, geologists, engineers, hydrologists) do not lead to inherently more restrictive regulations.
- No clear relationship can be identified between the restrictiveness of the regulations and the identity of the initiator of the regulation implementation process.
- "Reactive" regulations—in other words, those that are implemented to address a specific problem that is already occurring—tend to be more restrictive than preventative regulations.
- Often, planners believe that karst regulations are effective methods of achieving a particular goal, even if they haven't actually witnessed it.
- Strategic behavior does not seem to be an issue in the process of deciding whether or not to implement karst land use regulations. Indeed, analysis suggests that there is no rational reason to engage in such strategic behavior in the first place, since the presence of karst-aware land use regulations does not appear to put a

municipality at an economic disadvantage relative to neighboring towns that do not employ such regulations.

- In areas where local populations are more heavily dependent on natural resource exploitation as an economic foundation, attempts to manage and protect the local karst could very easily interfere with economic development for the local population. Successfully achieving both goals may well require an approach that differs from the traditional protected area approach.

Ultimately, the role of regulation in karst terrains is twofold: first, to protect human-built structures from damage caused by some of the more hazardous aspects of karst terrains, like sinkholes or flooding; and second, to mitigate and prevent damage to local karst systems and the resources (for example, groundwater supplies or tourist attractions) that they provide. The previous chapters show that there is no single, unified approach to the implementation of this type of regulation, and that these differences cannot be completely explained by factors such as region, population, the extent of the local karst system, or the nature of the specific karst-related issues. Nor are the impacts of karst regulations clear and unambiguous: this book also suggests that the results of implementing karst-aware land use regulations are often not the results expected by planners or other land use professionals.

By examining a wide range of karst-aware regulatory techniques in diverse settings, this book connects much of the existing research on land use in karst terrains under a single, unifying umbrella, while simultaneously offering new insights into the development of these regulations and their impacts on the human settlements that choose to implement them. Most of the prior research into karst land use regulation focused on a single type of regulation or a particular environment, like protected area management, and generally has produced a great deal of valuable knowledge about karst management under specific conditions: In protected area management, see Urich et al. (2001), who describe how conflicts between federal governments and local populations can develop in lands subject to protected area management plans; or Jepson et al. (2002), who note the inverse correlation between a landscape's economic potential and the likelihood that resource protection efforts will be successful. Likewise, Dinger and Rebmann (1986), Butler (1987), Dougherty (1993), Fischer (1997), Davis (1997), Reese et al. (1997) and Barner (1999) all examine karst-aware land use regulations in specific locations, each studying different stages of the regulatory process as it unfolded in different locations. Several of these authors examine karst land use regulations from a historical or developmental perspective: motivations ranged from protecting local groundwater supplies to flood prevention to a desire to reduce legal action against the city. None of these motivating factors are unique to any of the locations in which these studies were conducted, and each author treats each case study as an isolated incident, without placing the regulation in the wider context of karst land use regulation. Davis (1997) conducted a wider-ranging study, in geographical terms; however, his study was limited to regulations governing landfills in karst terrains. Fischer (1997) used his vantage point as a land use planning practitioner to evaluate several different approaches to karst land use regulation in Pennsylvania and New Jersey, and determined that the NNJRC& D model ordinance was best able to balance competing demands (economic and environmental), and therefore offered the best chance of success. It is worth noting that Fischer's and Davis' approach differs from the others in that theirs were more broadly defined study areas. Other authors, like Rubin (1992), LaMoreaux et al. (1997), and Richardson (2003), have undertaken analyses of karst land use regulation on a regional or nationwide level; however, out of necessity these efforts tend to take a very broad view, and do not generally delve into the details of karst land use regulation.

This pattern—narrowly focused, detailed studies of a single location existing side by side with broad, general analyses of the state of karst regulation on a regional or national level—is repeated throughout the karst policy literature; however, to date there has been little effort to integrate this knowledge into a broader understanding of karst land use regulation in general. This book represents an effort to begin to bridge that gap by combining both types of studies; indeed, in doing so we are presented with a muddier picture than we might have expected, with some results that are at first unclear, or even seem to contradict each other. Many of these results provide promising avenues for future research, which are briefly discussed at the end of this chapter.

Karst regulations are not developed and implemented in a vacuum. There must be a perceived threat, either to or from the karst formations underlying a municipality that chooses to regulate land use in this way. The results discussed here offer insight into the role of humans in generating or exacerbating threats to karst landscapes, or reacting to threats posed by those landscapes. In this chapter, these results will be described and analyzed in such a way that a clearer understanding of karst-aware land use regulations can emerge. On a practical level, the idea is to identify and discuss the contributions of various inputs into the land use regulation process in a way that enables planners or other land use professionals to make sensible, research-based decisions on how such legislation or regulation should be constructed in their own jurisdictions. But the larger goal is to further develop our understanding of how humans react and how human settlements change in response to both the presence of karst, and to the use of this particular type of land use regulation.

Indeed, it should be emphasized that what is presented in this chapter is not intended to be viewed as a completed framework, and instead should be considered a work-in-progress or a starting point, as there is certainly much work yet to do. For example, there are almost certainly some variables that are not examined within this book that may warrant inclusion once more research has been conducted. Also, it should be clarified that it is not the intent of this book to offer a step-by-step recipe for implementing karst-aware land use regulations, or a "fill-in-the-blanks" template for such regulations, along the lines of the Northern New Jersey Resource Conservation and Development Council document discussed in Chapter 2 of this book. That document is successful because it is intended for communities in a particular region, where geologic conditions and other variables do not differ widely between towns. On the other hand, throughout this book it is argued that communities located in karst areas in different regions will have different needs to consider, as well as different initial conditions and different influences on the policy process.

Karst Systems, Human Systems, and Where They Meet

In the end, the subject of this book is really a system of systems: it is the interaction of karst systems and two types of human systems—specifically urban systems, or at the very least clustered settlements, and policymaking systems. The components of karst systems include limestone or carbonate bedrock, precipitation, temperature, and carbon dioxide derived from organic material (this is usually found in the overburden, but not always) (Fig. 6.1). Urban system components include people, land, artificial structures, economic inputs, outputs, and byproducts (including fertilizers, industrial wastes and pollution, trash generated by packaged consumer goods), and other wastes. When urban systems are located above or very near to karst systems, the two systems interact to become a single system—for example, groundwater is withdrawn to help fuel growth; land subsidence damages human-made structures and opens new pathways from the surface to the aquifer; more surface-level pollutants end up in the groundwater. Urban systems are also usually at least partially governed by constraints and rules. These constraints are produced by the local policymaking system, the nature of which can differ greatly from locality to locality. In general, inputs include public opinion, business and economic interests, ambitions and goals of the policymakers themselves, and specialized technical analysis. This is a very broad generalization, of course; in many places, the local policymaking system is quite complex. Ultimately, these constraints can be produced by policymaking systems to govern or regulate the ways in which an urban system interacts with a karst system.

Certainly, urban systems, karst systems and policy systems meet several of the traditional definitions of systems. The system under examination in this book includes the components and interrelationships of all three of these systems. As von Bertalannfy points out, all living systems are open systems; the system under examination here is as well. Forces and entities external to the system are able to provide inputs and influence the end state. Beyond the simple open/closed system dichotomy, this system meets the definition of a mechanical system (systems that are driven by changes to a set of relatively simple parameters). It could also be argued that it meets the definition of a social system as well; however, while social systems do address the interaction of humans with their physical artifacts, they also tend to emphasize symbolic artifacts as well, which are not as important here. The most significant difficulty in applying system theory to this research is that the most important component of the system—humans—is also its least predictable component. However, this is perhaps the single most common difficulty in conducting research in any of the social sciences, and should not stand in the way of drawing sound conclusions from the data gathered here (von Bertalannfy 1973).

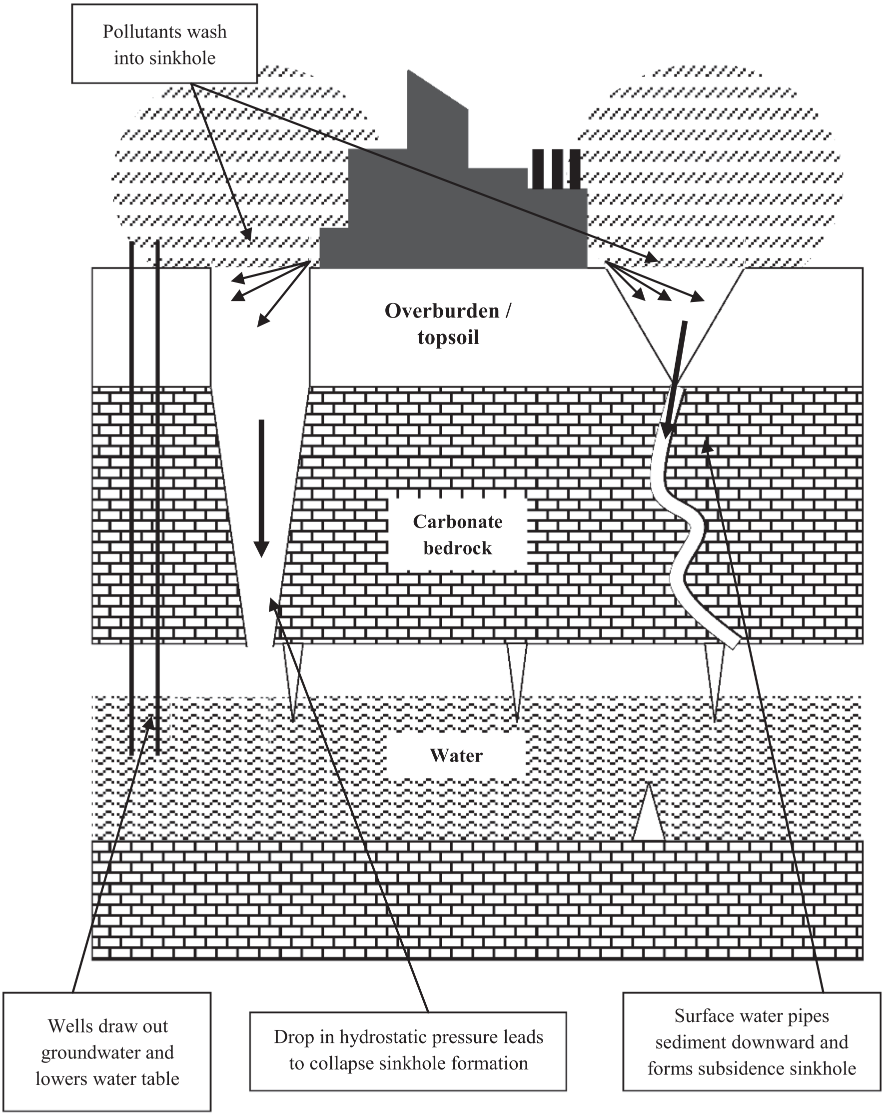

Fig. 6.1 A karst system (not to scale)

Inputs

In the preceding chapters, this text examined the effects of certain inputs into the karst land use regulating process and their impacts on both the regulations themselves and the human systems to which they were applied. Specifically, this research explored how setback-style sinkhole ordinances affect residential structural density in sinkhole-prone areas; it examined whether there were economic incentives for policy makers in Pennsylvania to engage in strategic behavior when deciding whether or not to implement karst-aware land use regulations; and it looked at the challenges facing karst protection efforts in Romania's Apuseni Natural Park, in particular those relating to a lack of enforcement authority. It also examined the perceived impacts of karst-aware land use regulations, as viewed from the perspective of planners, geologists and other land use professionals in the United States.

Figure 6.2 depicts a general conceptual framework of the process of karst-aware land use regulation; it is highly generalized, and the specifics will vary widely from locality to locality. This section will begin with an examination of a group of inputs into the regulation development process. The discussion is limited to a handful of inputs that were considered important for one of two reasons: each input was either a significant factor in the process of writing and developing these regulations, or it seems to have an unexpectedly weak impact on the process. Precisely quantifying the significance of each input to the system is almost certainly an impossible task; indeed, it is challenging enough to simply identify each input. However, based on the results of the research described in the preceding several chapters, we can see that some inputs generally seem to have greater impact on the regulatory process and results than others. Some of the more interesting inputs from both groups are described in this section.

Technical expertise: In Chapter 3, input from non-elected professionals like geologists and hydrologists was cited by a large number of respondents as being a critical factor in the development of karst-related land use regulations. This is not surprising, as Sabatier emphasized the importance of specialist knowledge ("policy-oriented learning") in his Advocacy Coalition Framework of the policy process (Sabatier and Jenkins-Smith 1988). Results suggest that consulting technical experts has significant benefits (i.e., acquisition of the theoretical and practical knowledge required to target and design effective karst-related regulations) that are not accompanied by significant drawbacks (these professionals do not seem to be inclined to promote excessively restrictive regulations, even as their influence over the process increases). But because of the generally intangible nature of the benefits of technical expertise, its impact on the regulation writing and implementation process is almost impossible to quantify. There do seem to be some tangible results of higher levels of influence from non-elected professionals: Survey results also show that the use of extra steps in the permitting process, of dumping and waste disposal regulations, and of fertilizer and chemical application regulations is more frequent in municipalities where non-elected professionals were more influential on the karst land use regulation process.

Attitudes of planners and land use professionals: The survey results in Chapter 3 demonstrated that the attitudes of land use professionals are critical in the process of crafting and implementing karst land use regulations. Most, generally feel that regulating development on karst or near karst features is appropriate; opinions diverge on the question of what will happen as a result of any such implementation. Counties, cities and towns without karst-aware land use regulations on the books are more likely to employ land use professionals who expect karst land use regulations

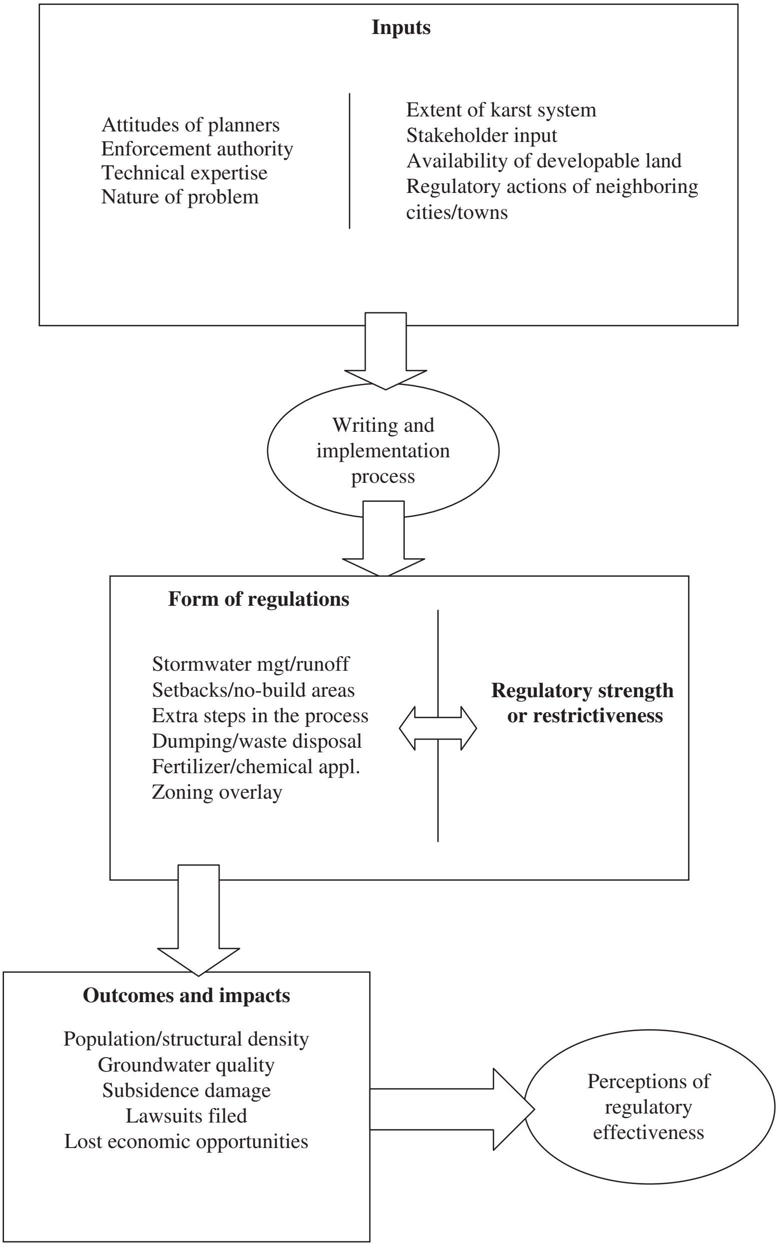

Fig. 6.2 The karst regulatory process

to result in mostly negative outcomes than are municipalities where such regulations can be found. Planners and land use professionals must be convinced that benefits will accrue, or the regulations are highly unlikely to get off the ground; this is almost certainly due to their role as "gatekeepers" in the process.

Enforcement authority: There are repeated examples of the importance of enforceability throughout this book; these include the Apuseni Natural Park, Brooksville Ridge Cave, and the responses of land use professionals to the survey described in Chapter 3. Without the ability to enforce karst protections, stakeholders with an incentive (particularly a financial incentive) to ignore your regulations are very likely to do exactly that. There is a strong existing literature that details the importance of enforcement in a protected area context. Even beyond that context, both the existing literature and interviews suggest that enforcement authority is also a factor in karst land use regulation in non-protected areas in the United States; for example, a comprehensive plan that attempts to control growth in carbonate areas is not likely to be effective absent a zoning ordinance to implement and enforce the priorities of the comprehensive plan (Day 1996; Jepson et al. 2002; Kueny and Day 2002). Additionally, subdivision and land development ordinances with karst-related components are easier to waive than zoning ordinances, and thus do not provide the same level of protection or enforcement authority.

In the study of Brooksville Ridge Cave, we saw that the county environmental office's ability to affect development plans for the land above the cave hinged on its ability to enforce the comprehensive plan and the groundwater protection ordinance; in this particular case, that was achieved by granting the environmental office the responsibility for conducting reviews of all residential and commercial development proposals, and to at least temporarily hold up projects that do not conform to local ordinance requirements. Enforcement-related issues may also have come into play in the case studies conducted in Kentucky, Missouri, and Pennsylvania that are described in Chapter 4. The weak results obtained in Pennsylvania suggest that this may be a particular problem there; due to the presence of the "strength" variable, it is reasonable to conclude that any enforcement issue is likely completely separate from the issue of regulatory stringency. This in itself is not proof of the existence of such an effect, but does provide ample reason to pursue it further.

Nature and "framing" of the problem: There are always more worthwhile public policy goals than there are resources to implement them. Different policy ideas are always in completion with each other for those resources; to that end, persuasive communication becomes paramount. "Framing" the discussion by defining the problem at hand in the terms that are more difficult to argue against will go a long way toward passing some sort of karst land use regulation.

Of course, effective framing should not be deceptive; ethical questions aside, this would conceivably result in regulations that did not address the important karst issues at hand. The nature of the specific karst problem quite naturally has a strong influence on the character of the land use regulations; addressing a groundwater contamination issue, for example, would require a different (if partially overlapping) set of tools than addressing a land subsidence problem. Results from the survey suggest that developing and implementing karst regulations is more likely to succeed if the underlying problem is highly visible, and if the proposed regulations can be readily connected to that specific problem. But even when the problem is visible and urgent, regulation-based solutions can easily fail to win approval if they are not properly framed. Contamination of groundwater resources and structural damage from land subsidence seem to be effective ways to frame the problem.

Stakeholder input: In this case, the term "stakeholder" is given a broad definition, and includes both local residents and those with an economic interest in the location (i.e., the construction industry, or resource users). The influence of each group of stakeholders varies widely. The results suggest that, for the most part, local residents do not seem to have a major influence on the development and implementation of karst regulations; the ones who do, are generally the ones who are both well-informed and most likely to be affected by such regulations. This group may not be representative of the general population. Data collected from follow-up interviews indicate that this can change with time, through public education programs; one respondent argues that such education programs can help preserve the regulation itself by mitigating any shifts in political priorities that occur with changing administrations (for example, a new mayor may be more sympathetic to the perspective of the construction industry than her predecessor; in that case, a voting public with a well-developed understanding of karst and the need for its protection can act as an obstacle to weakening existing regulation).

Follow-up interviews indicate that the construction industry is generally hostile to such regulations; however, the survey results suggest the industry is not always able to exert a significant amount of influence over the process (whether this is by choice or not is unclear). According to the survey, in some cases (less than 20%) construction interests are the most influential group in the process of developing regulations, but the construction industry was one of the least-frequently selected responses for the question of which group or entity had the most influence on the process. This strongly suggests that construction industry opposition can be overcome by those wishing to implement karst-related land use regulations, and fear of such opposition should not be a major factor in the process of developing karst-aware land use regulations.

Extent of the karst system: The size of the underlying karst system seems to play a role in determining the form of the karst-aware land use regulations that are ultimately implemented, but not on the restrictiveness of those regulations. According to the survey results in Chapter 3, municipalities with more extensive karst systems were more likely to employ mandatory setbacks/non-buildable areas and dumping/waste disposal regulations than those with less extensive karst; simultaneously, there is no strong connection between the extent of a particular karst system and the strength of the karst regulations that are ultimately implemented.

Of course, there are often difficulties in determining exactly how extensive a local karst system is, as demonstrated in the Brooksville Ridge Cave case study in Chapter 5. In that instance, the Hernando County Planning Department and the Board of County Commissioners found themselves trying to evaluate two conflicting, expert-generated estimates of the cave's size. It is a simple matter to imagine that most municipalities would lack accurate and reliable information on the size of the karst systems below the city limits; in some cases, there are simply not enough resources to conduct the appropriate tests, while in others city officials may not want to know specific details about the karst system, for fear that such knowledge could constrain them from pursuing plum projects. And even if city officials are able to get high-quality data, they often need assistance interpreting and understanding it.

"Keeping up with the neighbors," or the need for strategic behavior: It is appropriate to take into consideration what neighboring municipalities have done with regard to regulating development on karst terrains, but only to a point. Follow-up interviews with planners and land use professionals suggest that the experiences of other towns can be illuminating in identifying effective regulatory techniques for preventing karst degradation and aquifer damage. One reason for this is that towns in close proximity to each other are more likely to be subject to the same external influences (geologic, economic, political, etc). However, results from Chapter 4 suggest that there is little reason to consider the mere existence of such regulations in neighboring towns as a factor in deciding whether to implement karst-aware regulations or not, as they seem to have no statistically detectable impact on indicators of economic growth and health; additionally, results from the survey confirm that this is generally understood by land use professionals to be the case. This contradicts expectations rooted in economics and game theory, and may indicate that karst regulations are generally not sweeping enough to have a widespread impact on growth and development patterns.

Outcomes

This book does not examine the effectiveness of karst-aware land use regulations with respect to karst protection, or at least not directly (i.e., through water quality tests, or quantifiable measures of cave protection). Instead, it looks at indirect measures of the effectiveness of karst protection, generally in terms of regulatory impact on human systems and human behavior. This includes settlement patterns, density, and economic considerations, among others. This section includes discussion of these outcomes and their implications.

Expectations and perceived outcomes: Survey results and follow-up interviews indicate that the most commonly observed outcomes of implementing karst regulations are a decline in damage from subsidence, and an improvement in groundwater quality. However, as was shown in Chapter 3, these outcomes are expected to occur more frequently than they are actually reported to occur. Whether this is due to inadequate methods of regulation or something else is not yet known; indeed, it is not even known if these perceptions are in fact accurate. It is entirely possible, for example, that groundwater quality improves far more frequently than survey respondents reported. This suggests that expectations for the benefits of implementing karst-related land use regulations may be too high, perhaps leading to an eventual consensus that the regulatory route is not adequate for managing development on karst, and that the benefits of these regulations are not worth the time and effort of implementation.

Lawsuit prevention: According to survey results and follow-up interviews, karst-sensitive land use regulations seem to be an effective way to discourage lawsuits filed against the city or county. Typically, these lawsuits arise from unanticipated land subsidence activity that significantly damages property. In Lexington-Fayette County, for example, reducing lawsuits filed against the county was an explicit goal of the development and implementation of the county's sinkhole ordinance (the ordinance takes the form of a minimum setback/non-buildable area restriction); the ordinance has been successful in this goal (Rebmann 2006). The presence of such ordinances or similar regulations may make it more difficult for potential plaintiffs to successfully argue that any subsidence damage to structures built near a sinkhole is actually the city's fault for negligently issuing a building permit for an unsafe area.

Economic growth and development: Higher housing costs and lost development opportunities were both cited by several respondents to the survey as expected outcomes of implementing karst regulation. However, the same survey results indicate that these outcomes are not often observed. While it is true that both of these outcomes are difficult to quantify, or at least present difficulties in identification of the primary cause, it is still possible to draw some conclusions from the data gathered for this book. Data from karstic areas in Pennsylvania suggest that the implementation of karst regulations does not, in fact, have a statistically significant impact on median housing value within the community. As for lost opportunities for development, these can be directly tied to karst regulations only via anecdotal evidence at best. However, if we use the total number of residential building permits issued by each town as a proxy variable for development opportunities, we see there is once again no statistically significant difference in the number of permits issued between municipalities that regulate development on karst and those that do not.

What are the implications of this finding? There are several possibilities. First, the fact that karst regulations do not seem to affect median housing value suggests that perhaps the "amenity factor" of more open space that should result from implementation and enforcement of karst land use regulations is generally not an important consideration in a market-based determination of home values. Conversely, the land use restrictions imposed by karst land use regulations do not seem to act as a drag on home values either. Residential building permit data suggests that karst regulations do not generally dampen demand for new housing, or encroach on the profitability of new residential projects. Perhaps the residential construction industry is better able to adapt to external conditions and forces than is widely assumed; it is also possible that the regulations are generally ineffective, go unenforced, or have only limited geographic applicability (and therefore only limited impact).

Population and structural density: Responses from the survey suggest that even though a sizable minority of respondents expected to see population density decrease as a result of implementing karst regulations, very few actually observed this outcome. However, if one looks at block-level data from municipalities in Kentucky and Missouri, one sees the expected relationships between sinkholes with mandatory setbacks and population/structural density (i.e., areas with lots of sinkholes are less dense). There is a counter-intuitive component to these results, namely the positive correlation between sinkhole density and residential structural density;

however, there are several potential explanations for this phenomenon (discussed at the end of Chapter 4).

The results from Chapter 4 suggest very strongly that, up to a point, setback and non-buildable area ordinances do act as a drag on density growth rates in sinkhole-prone areas. So, why wasn't this outcome reported more frequently in the survey results? The answer to that question may lie in the fact that these effects are simply too localized to be widely noticed, or that changes in density are perhaps too subtle and occur over too long a time period to be accurately perceived by most casual observers on the ground. Densities take a long time to change, especially in American urban areas where zoning codes are often strongly focused on maintaining a particular density level. In those cases, densities can drop quickly as people move out and buildings are demolished, but adding significant amounts of people and structures take a bit more time. Densities are more likely to change rapidly on the outskirts on an urban area, where there is generally more available land and often government policies in place that are aimed at attracting new residents and businesses.

Regulatory strength and restrictiveness: Most survey respondents describe their local regulations as either "not very restrictive" or "somewhat restrictive." There is some relationship between perceived restrictiveness and the increased rates of implementation of many commonly applied regulatory tools (this relationship does not apply to stormwater runoff regulations, which are almost universally applied); however, whether or not regulatory restrictiveness has any tangible impact on the urban system itself is an open question. Using a consistently applied, even if somewhat subjective, definition of regulatory restrictiveness and applying it to data from Pennsylvania, we see that restrictiveness (represented by the *strong* binary variable) had no impact on either median home values or on the number of residential construction permits issued. As mentioned earlier in this chapter, this fact suggests the possible existence of an issue with enforcement, which may almost alone explain the results obtained from the Pennsylvania data set.

Form of regulations: Survey results suggest that stormwater runoff regulations are the easiest type of karst-related land use regulation to get implemented; follow-up interviews indicate that the reason for this is the straightforward nature of the problems they generally address, as well as the straightforward nature of the regulations themselves. The fact that stormwater runoff laws are also needed in non-karstic terrains is significant as well; city residents understand the general problems that uncontrolled surface water flow can cause and are generally open to the implementation of such an ordinance. Respondents seem to generally feel that, if done properly, stormwater runoff and management ordinances can be effective tools in karst land use regulation. They are extremely common in Pennsylvania local land use regulation, possibly the most common.

While mandatory setbacks/non-buildable areas are based on a similarly straightforward idea, interviews suggest that it can be difficult to make these effective, unless it is difficult for developers and landowners to get variances. In order for that to occur, the body responsible for issuing variances must be sympathetic to the goals of regulating land development and use in karst areas; it also must have the ability to resist political pressure to grant variances in cases where a variance would be inappropriate (Rebmann 2006). However, statistical analysis conducted in Chapter 4 suggests otherwise, that in fact these ordinances can have some effect on human density near sinkholes.

Follow-up interviews suggest that zoning ordinances may often be too blunt a tool for karst-related land use regulation. This is due to the oft-localized nature of karst landform development; regulations intended to manage development near such landforms may not be appropriate for all development in a given area. Instead, it may be best to simply require developers working in a vulnerable area to hire a geologist for a site-specific analysis.

Possible Future Directions

At the beginning of this chapter, it was emphasized that these conclusions should not be considered a comprehensive, finished framework for developing karst land use regulations. There is still plenty of work to be done in our goal of understanding the relationship between karst systems, urban systems and policy systems. Some potentially promising avenues for future study include:

- A more generalized approach to the understanding of how karst regulations are affected by constraints on the availability of developable land. While the results from Lexington-Fayette County are fairly clear, it is by no means obvious if those results are applicable to other cities where land availability is constrained. It is generally accepted that local real estate markets can be highly affected by extremely localized conditions; it would therefore be particularly useful to look at cities where any such constraints are the result of the surrounding natural landscape, for example, as opposed to artificially imposed constraints like an urban growth boundary. This would enable us to better model the effects of restrictive karst land use regulations on any localized pool of available land.
- A more detailed exploration of the economic impacts of implementing karst-aware land use regulation. The results discussed in earlier chapters of this book are interesting but by no means definitive. These sorts of analyses are particularly sensitive to questions of data and modeling; certainly, pursuing other approaches to asking this question will provide a more robust understanding of the issue. In particular, a study of whether and how such regulations affect commercial and industrial development projects would be illuminating.
- An examination of the effectiveness of different types of land use regulations, in terms of how well those regulatory tools protect karst landforms and aquifers. While it is true that this type of study was beyond the scope of this book, that in no way lessens its importance as a subject for future study. An objective measurement of the protective potential of various regulatory approaches, and the conditions under which they are most effective and least effective, would provide planners and regulators with a critical piece of information that would enable them to more rapidly develop and deploy appropriate, effective land use regulation for local karst terrains.

- An examination of how well karst-aware land use regulations are actually enforced. One of the most significant conclusions of this research is the importance of enforceability of any regulations that are implemented to control land use near karst landforms. We currently lack any detailed understanding of the issues involved in effective enforcement of karst regulations, or even of whether enforcement is generally attempted in the first place. By systematically studying the factors that influence the ability or desire of local governments to enforce karst regulations, we can begin to develop better strategies for enforcement that would lead to more effective protection of karst landforms and the underlying aquifers.

Ultimately, this framework is intended to address questions of balance between human needs and nature's needs. How far can humans go in exploiting their natural resources—like karst systems, for example—before they are destroyed? What society-level lifestyle choices will we have to make in order to protect our underground drinking water supplies? And are we even willing or able to make those changes?

Answering these questions will take more research, both into karst itself and into the myriad questions surrounding land use regulation in karst terrains. That is why the further development of this framework is important: it will act as a tool that will give us the opportunity to build on previous research and existing knowledge and find the answers to these questions. However, the questions outlined above are only a starting point. Given the critical importance of karst resources to both scientific research (especially with regard to climate change) and water accessibility for about a billion people and counting worldwide, it is clear that human–karst interaction is a vital policy question that humankind will have to address more thoroughly in the very near future.

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Appendix A
A Glossary of Karst Terminology

Aquifer – an underground layer of earth or bedrock that stores and supplies water.

Calcite – the primary component of limestone and the most common of the calcium carbonate minerals.

Catchment – an area in which surface water collects and eventually drains into a water feature, like a river or spring.

Cave – a natural subterranean opening or void that is large enough for a human to enter. Often, but not always, formed by karstic processes.

Column – a speleothem that extends from the floor to the ceiling of a cave.

Conduit – an underground opening in the bedrock through which groundwater is conducted.

Decoration – cave features like stalactites, stalagmites, helictites and popcorn. Usually formed via calcite precipitation.

Discharge – outflow drainage from aquifers. In a karst context, can be manifested through caves or springs.

Doline – see *sinkhole*.

Dolomite – a mineral commonly found in carbonate rocks. Some karst landscapes are composed primarily of dolomite.

Epikarst – a layer of karstified carbonate rock found directly beneath the topsoil.

Fissure – a narrow crack or opening in the bedrock.

Groundwater – water stored below ground in the aquifer, generally below the level at which all voids and openings are saturated.

Helictite – an irregularly-shaped speleothem that can grow both vertically and in an angular form. Helictites are generally smaller formations, and specimens longer than four inches are rare.

Karst – a type of landscape formed by solution processes on carbonate bedrock. Development of a karst landscape requires warm temperatures, adequate precipitation, a source of carbon dioxide in the topsoil, and carbonate bedrock. They are characterized by landforms that include sinkholes, springs and caves.

Karstification – the process of forming a karst landscape.

Paleokarst – fossilized, inactive karst features.

Permeability – a property of rock that describes the ability of water to pass through it.

Porosity – a property of rock that refers to the number of small voids existing within it.

Pseudokarst – a landscape with karst-like features that have not been created via karstification.

Recharge – the process of intake of water into an aquifer.

Sinkhole – a common type of karst landform, created by the subsidence of soils and rock at or near the land surface into empty spaces below.

Solution – in a karst context, a water-driven process by which karst landforms are created. Occurs when a weak carbonic acid solution reacts with carbonate bedrock, resulting in the gradual widening of cracks and fissures in the rock.

Speleothem – a vertical cave feature formed by the precipitation of calcite. Includes both stalactites and stalagmites.

Spring – a surface-level representation of the aquifer.

Vadose zone – an area where voids in the bedrock are filled with air and through which surface water travels on its way to the aquifer.

Appendix B
Results of a Survey of Land Use Professionals Working in Karstic Areas of the United States

Conducted between October 2006 and January 2007, and administered online via SurveyMonkey.com.

1 Are you familiar with karst?

	Response total	Percent
Yes	59	89.39
No	7	10.61
Total Respondents	66	
(skipped this question)	0	

2 By which type of organization are you employed?

	Response total	Percent
Local government	47	82.46
State government	6	10.53
Federal government	1	1.75
Private consulting/contracting	1	1.75
Other	2	3.51
Total Respondents	57	86.36
(skipped this question)	9	

3 This survey deals with local land use regulations. Please enter the name of the city or county on whose regulations you will be commenting.

Total Respondents	55
(skipped this question)	11

4 In which state do you work?

	Response total	Percent
Florida	24	42.11
Kentucky	6	10.53
Missouri	8	14.04
New Jersey	2	3.51
Pennsylvania	13	22.81
Tennessee	4	7.02
Total Respondents	57	86.36
(skipped this question)	9	

5 What is your job title?

Total Respondents	55
(skipped this question)	11

6 To the best of your knowledge does your city or town currently have any form of karst-related land use regulations on the books?

	Response total	Percent
Yes	32	56.14
No	21	36.84
Not applicable - I work at the state or federal level	4	7.02
Total Respondents	57	86.36
(skipped this question)	9	

7 In your opinion why has your city or town declined to enact karst-related land use regulation? (Select all that apply)

	Response total	Percent
Philosophical opposition to regulation in general	3	16.67
Fear of lawsuits	0	
Pressure from developers	3	16.67
Fear of losing opportunities for growth to neighboring towns without such regulations	1	5.56
There is no karst within the town limits	2	11.11
Citizen input	0	
Other (please specify)	11	61.11
Total Respondents	18	27.27
(skipped this question)	48	

8 Were you involved in the creation or implementation of karst-related land use regulations in your jurisdiction?

	Response total	Percent
Yes	16	45.71
No	19	54.29
Total Respondents	35	53.03
(skipped this question)	31	

9 Approximately how long ago were these karst regulations implemented?

	Response total	Percent
Within the last two years	5	14.29
Between two and five years ago	5	14.29
Between five and ten years ago	6	17.14
More than ten years ago	16	45.71
I don't know/I don't remember	3	8.57
Total Respondents	35	53.03
(skipped this question)	31	

10 In your opinion how serious in your community are the following karst-related issues?

	Total	Pct	Total	Pct	Total	Pct	
	Very serious		Somewhat serious		Not serious		Response average
Groundwater contamination	18	51.43	13	37.14	3	8.57	1.56
Flooding	11	31.43	15	42.86	8	22.86	1.91
Subsidence and property damage from sinkholes	15	42.86	14	40.00	5	14.29	1.71
Karst ecosystem protection	12	34.29	13	37.14	10	28.57	1.94
Cave protection	6	17.14	12	34.29	16	45.71	2.29
Total Respondents	35	53.03					

11 Please rank the following five karst-related issues in order of seriousness:

	Total	Pct	How serious?			Total	Pct	
	Most serious		←——→			Least serious		Response average
Groundwater contamination	17	48.57	10	3	4	0	0.00	1.82
Subsidence and property damage from sinkholes	8	22.86	11	6	5	4	11.43	2.59
Karst ecosystem protection	2	5.71	6	14	6	4	11.43	3.13
Flooding	7	20.00	6	7	12	2	5.71	2.88
Cave protection	1	2.86	0	4	6	22	62.86	4.45
Total Respondents	35	53.03						
(skipped this question)	31							

12 In your opinion how extensive is the karst system in your area?

	Response total	Pct
Not at all extensive – less than 10% of the total land area contains karst	2	5.71
Not very extensive – between 10% and 30%	6	17.14
Somewhat extensive – between 31% and 50%	15	42.86
Very extensive – more than 50%	11	31.43
I don't know	1	2.86
Total Respondents	35	53.03
(skipped this question)	31	

13 Which of the following karst landforms are present in your area? (Select all that apply.)

	Response total	Pct
Springs	33	94.29
Sinkholes	35	100.00
Caves	26	74.29
Sinking or disappearing streams	26	74.29
Other (please specify)	1	2.86
Total Respondents	35	53.03
(skipped this question)	31	

14 In your opinion how restrictive are the karst-related land use and development regulations in your jurisdiction?

	Response total	Pct
Very	4	11.43
Somewhat	15	42.86
Not very	12	34.29
Not at all	2	5.71
I don't know	2	5.71
Total Respondents	35	53.03
(skipped this question)	31	

15 (question removed)

16 To the best of your knowledge which of the following karst-related regulatory components are present in your jurisdiction's land use and development regulations? (Select all that apply.)

	Response total	Pct
Mandatory setbacks from karst features	19	57.58
An extra step in the permit approval process (for example, the county geologist is required to do an analysis and provide a recommendation)	17	51.52
Multiple extra steps in the permit approval process	9	27.27
A moratorium on new construction in areas where karst features are present	0	0.00
Stormwater drainage rules	30	90.91
Dumping and waste disposal rules	18	54.55
Fertilizer and chemical application rules	6	18.18
Other (please specify)	6	18.18
Total Respondents	33	50.00
(skipped this question)	33	

17 Which of the following factors was a goal of regulating development in karst areas? (Select all that apply.)

	Response total	Pct
Environmental protection	22	64.71
Groundwater protection	30	88.24
Cave protection	7	20.59
Desire to prevent property and structural damage	28	82.35
Desire to limit the legal liability of local government	11	32.35
Total Respondents	34	51.52
(skipped this question)	32	

18 Prior to the implementation of these karst-related land use regulations had there been any actual problems with some or all of the factors listed in the previous question or were these regulations implemented as strictly a preventative measure?

	Response total	Pct
Strictly preventative	11	33.33
Intended to address actual existing problems (please specify)	22	66.67
Total Respondents	33	50.00
(skipped this question)	33	

19 Who initiated the process of developing these regulations?

	Response total	Pct
Branch or department within local government	13	39.39
Branch of state or federal government	7	21.21
County or city commission, or local equivalent	5	15.15
Mayor or county administrator, or local equivalent	0	0.00
Environmental or science groups	1	3.03
Local residents	0	0.00
Other (please specify)	6	18.18
Total Respondents	32	48.48
(skipped this question)	34	

20 Who ultimately approved these regulations?

	Response total	Pct
Elected body (for example, county commission)	21	61.76
Elected official (for example, mayor or county administrator)	7	20.59
Appointed official	1	2.94
Career civil service official	1	2.94
Other (please specify)	4	11.76
Total Respondents	34	51.52
(skipped this question)	32	

21 How much time elapsed between the point at which the idea of regulating development on top of karst was first seriously proposed and the time those regulations were finally enacted?

	Response total	Pct
0–2 years	13	39.39
2–4 years	4	12.12
5–7 years	3	9.09
Longer	2	6.06
I don’t remember	11	33.33
Total Respondents	33	50.00
(skipped this question)	33	

22 Which of the following entities or groups had an influence on the process of designing the karst-related land use and development regulations in your jurisdiction? (Select all that apply.)

	Response total	Pct
Federal government	5	15.15
State government	19	57.58
Local elected officials	18	54.55
Local government departments (like the Water Department, for example)	27	81.82
Environmental or scientific groups (non-governmental)	14	42.42
Members of the building or real estate industries	6	18.18
Local residents	14	42.42
Other (please specify)	6	18.18
Total Respondents	33	50.00
(skipped this question)	33	

23 To what degree were these regulations influenced by non-elected professionals (i.e., scientists or engineers for example) working for or in conjunction with local government?

	Response total	Pct
Not at all	0	0.00
Slightly	4	11.76
Moderately	7	20.59
Strongly	16	47.06
I don't know	7	20.59
Total Respondents	34	51.52
(skipped this question)	32	

Please describe the nature of this influence if any:

By using educated professionals who believe in the protection of karst features we were able to gain (I feel) a greater influence.

Regulations reflected credible engineering and geologic knowledge and experience.

Engineering community had input.

Home-owners association meetings where county commissioners were invited.

Giving testimony to the Planning Commission

Such professionals on staff and via participation from citizens and special environmental interest groups having this professional background

Stormwater Taskforce involved professionals from the community

Mapping of potential karst areas and development of requirements for design of ponds, swales and underground utilities in proximity to these areas.

Input from developers and contractors

Report on Karst areas subject to flooding (USGS, FEMA mapping w/TVA and City

Permanent, full-time, professional Planning Staff drafted ordinance, City Engineer and Solicitors reviewed. Planning Commission resolved to recommend to City Council adoption of ordinance. City Council adopted subdivision and land development regulations including land suitability requirements.

County staff doing research on the problem

Provision of the science base for understanding groundwater, the aquifers in the state, the rate of recharge, etc., affected decisions prioritizing areas that are karst sensitive and in developing the land use regulations to protect them.

Township (city) Engineer was instrumental in working on our Karst Regulations.

In our case our organization worked by committee (of non-elected professionals) to develop a model ordinance. This ordinance has been adopted by many communities in our region.

This occurred 16 years ago

Direct meetings with the local TDEC office to develop stormwater regulations and coordination between county and state on injection well permits for stormwater. More codes to follow soon.

Very important

Input came from: City Planning (staff wrote ordinance), State Water Management district engineers, some public input from local residents with engineering/natural sciences backgrounds, and local real estate/development interests.

Geologist, soil scientist, hydro geologist, biologist, and others all have had a significant role in conducting solid science to be used in development of the rule.

Local land use planners and elected officials rely on authoritative opinions from geoscientists and engineers, published studies and other documentation from the USGS, FDEP, etc.

Some professionals in the region had identified karst topography as potential problem for septic field related ground water contamination.

Professional opinions were sought and provided to the BOCC (Educational).

Total Respondents	23
(skipped this question)	43

24 To what degree were these regulations influenced by pre-existing regulations relating to land use and development (like for example the presence of an urban growth boundary or other environmental regulations)?

	Response total	Pct
Not at all	13	39.39
Slightly	8	24.24
Moderately	5	15.15
Strongly	2	6.06
I don't know	5	15.15
Total Respondents	33	50.00
(skipped this question)	33	

25 Please describe the nature of this influence if any.

Karst regulations represented a new field of regulation.

Knowledge of related state regulations was used in pressuring the local elected officials to push for adopting similar regulation

New developments going into karst areas.

State regulation interface needs

States Inject Well Regs. . .TDEC is asked to review impacts in sinkhole areas

Part of comprehensive plan

City had previously passed Creek regulations governing increased setbacks. City was one of first in Florida to pass Stormwater Utility fee for city-wide stormwater improvements, including retrofitting storm drains, upgrading wastewater plant water disposal, etc.

State already had regulations about setback of septic systems from karst areas (sink holes etc.) which were incorporated in development reviews.

Previous goals and objectives of our earlier comp plan and land development regulations.

Total Respondents	9
(skipped this question)	57

26 To what degree were these regulations influenced by local residents?

	Response total	Pct
Not at all	6	18.18
Slightly	11	33.33
Moderately	8	24.24
Strongly	3	9.09
I don't know	5	15.15
Total Respondents	33	50.00
(skipped this question)	33	

27 Please describe the nature of this influence if any.

Residents who are concerned for the general quality of the county's environment always have a voice in the decision making process.

Home owners association meetings where commissioners were invited, also news paper articles

Local residents participated in the process; were generally supportive.

Public hearings were held where the public spoke

The reporting of the various incidents provided sufficient documentation to warrant investigation of appropriate regulations and safeguards.

Concerns raised relative to stormwater damage and the adverse impact on local drainageways, streams and existing infrastructure.

Where houses have been subject to flooding, there was major clamoring to solve problems. . .buy-outs and identification of flood limits around sinkholes

Clearly, the public is concerned about the occurrence of sinkholes as it is a regular 'phenomenon' due to subsurface conditions, location between three bodies of water, and the early, dense urban development of the City pre-federal, state or local land use regulation. City Planning, Zoning and Engineering personnel took the lead develop and enforce regulations in the interest of the public health, safety and welfare.

Constant complaints on the failure of government requiring permits up front - educational process on all parties

Public forums, strong opinions voiced

City has small vocal environmental movement.

Some in community reflected same information as regional professionals, and general concern with ground water contamination.

A few residents are affiliated with environmental groups, which put on educational presentations.

Public input was a continuing part of the process of developing land use regulations, through the comprehensive planning review process.

Total Respondents	14
(skipped this question)	52

28 In your opinion which of the following entities or groups had the most influence on the process of developing and implementing karst-related land use regulations?

	Response total	Pct
Federal government	0	0.00
State government	6	18.18
Local elected officials	1	3.03
Local government departments (like the Water Department, for example)	17	51.52
Environmental or scientific groups (non-governmental)	2	6.06
Members of the building or real estate industries	1	3.03
Local residents	1	3.03
Other (please specify)	5	15.15
Total Respondents	33	50.00
(skipped this question)	33	

29 In your opinion which of the following entities or groups had the least amount of influence on the process?

	Response total	Pct
Federal government	17	51.52
State government	1	3.03
Local elected officials	2	6.06
Local government departments (like the Water Department, for example)	1	3.03
Environmental or scientific groups (non-governmental)	1	3.03
Members of the building or real estate industries	10	30.30
Local residents	1	3.03
Total Respondents	33	50.00
(skipped this question)	33	

30 In your opinion is it appropriate for a municipality to attempt to regulate or manage development near karst landforms?

	Response total	Pct
Yes	32	96.97
No	0	0.00
Don't know/no opinion	1	3.03
Total Respondents	33	50.00
(skipped this question)	33	

31 In your opinion are the karst-related land use regulations in your jurisdiction effective?

	Response total	Pct
Yes	23	67.65
No	6	17.65
Don't know/no opinion	5	14.71
Total Respondents	34	51.52
(skipped this question)	32	

32 In your opinion which of the following are likely outcomes of implementing karst-related development restrictions in a city of town? (Select all that apply.)

	Response total	Pct
An increase in residential land values	9	18.37
An increase in housing costs	17	34.69
A decline in new development projects	9	18.37
A decline in population and structural density	7	14.29
A decline in development-related lawsuits filed against the city	8	16.33
An improvement in groundwater quality	37	75.51
Some other outcome (please specify)	14	28.57
Total Respondents	49	74.24
(skipped this question)	17	

33 In your opinion to what extent did the existence of karst-related land use regulations (or lack thereof) in neighboring towns affect the process of developing and implementing karst regulations in your municipality?

	Response total	Pct
It was the most important consideration	0	0.00
It was an important consideration, but not the only one, and not necessarily the most important one	4	8.70
It had some impact, but not a significant amount	10	21.74
It had no impact whatsoever	32	69.57
Total Respondents	46	69.70
(skipped this question)	20	

34 From the following list please select the impacts your town or city actually experienced after enacting karst-related land use regulations. ***__Please select ONLY impacts that you personally can attest to.***__ **(select all that apply)**:

	Response total	Pct
Higher housing costs	3	11.11
Lost opportunities for growth, as new development projects migrated to neighboring towns without regulation	2	7.41
An increase in lawsuits filed by landowners and developers against the city	0	0.00
An improvement in groundwater quality	5	18.52
A decrease in damage to structures from new sinkholes	9	33.33
A decrease in population density	2	7.41
I haven't witnessed any impacts of the karst development regulations	8	29.63
Some other outcome (please specify)	11	40.74
Total Respondents	27	40.91
(skipped this question)	39	

35 In your opinion can anything be done to improve the effectiveness of karst land use regulation in your jurisdiction?

	Response total	Pct
No	10	29.41
Yes (please elaborate, if possible)	24	70.59
Total Respondents	34	51.52
(skipped this question)	32	

Color Plates

Plate 1 Big Mouth Cave, Withlacoochee State Forest, Brooksville, Florida. Photo by Jason Polk

Plate 2 Crayfish in Ocala Caverns, Ocala, Florida. Photo by Jason Polk

Plate 3 Blowing Hole Cave, Withlacoochee State Forest, Brooksville. The gate was designed specifically to allow for bats to access the cave. Photo by Jason Polk

Plate 4 Harney Road sinkhole, Hillsborough County, Florida. This was caused by an underground rupture of a sewage pipe. Photo by Jason Polk

Plate 5 Sabertooth Sinks, Lecanto, Florida. These sinks are a pair of large solution tubes that eventually lead down to a cave. Photo by Jason Polk

Plate 6 Epikarst landscape on the Ozello Karst Plain, near Crystal River, Florida. Photo by Spencer Fleury

Plate 7 Epikarst formation near Crystal River, Florida. Photo by Spencer Fleury

Plate 8 Uvala in Kentucky, near Mammoth Cave. Photo by Jason Polk

Plate 9 An appearing stream discharging from the side of Cedar Sink, Kentucky. Photo by Jason Polk

Plate 10 Interior of Cedar Sink. Note the flowing water. Photo by Jason Polk

Plate 11 Bottom of Cedar Sink. Photo by Jason Polk

Plate 12 A sinking stream at the bottom of Cedar Sink. The stream feeds into the nearby Green River. Photo by Jason Polk

Plate 13 A bat in Mammoth Cave, Kentucky. Photo by Jason Polk

Plate 14 A karstic landscape near the Danube River, southwestern Romania. Photo by Jason Polk

Plate 15 A cave opening in southwestern Romania. Photo by Jason Polk

Plate 16 A karst landscape near Scarisoara, Romania, in the Apuseni Mountains. Photo by Jason Polk

Plate 17 The entrance to the Ice Cave at Scarisoara. Photo by Jason Polk

Plate 18 A stream exiting a cave opening near Scarisoara. Photo by Jason Polk

Plate 19 Bones inside Ursilor Cave, Romania. Photo by Jason Polk

Plate 20 A tufa deposit on the bank of Cedar Creek, near Front Royal, Virginia. Photo by Jason Polk

Plate 21 Blue Springs, near Strasburg, Virginia. Photo by Jason Polk

Plate 22 The entrance to Ogden's Cave, Strasburg, Virginia. Photo by Jason Polk

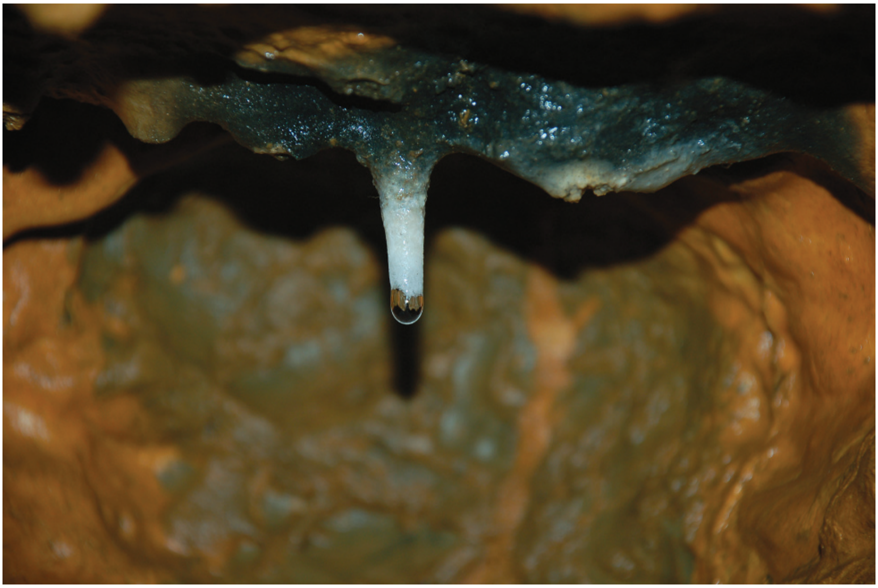

Plate 23 A soda straw inside Ogden's Cave. Photo by Jason Polk

Plate 24 A sinkhole-pocked landscape in Romania's Apuseni Mountains. Photo by Monica Exner

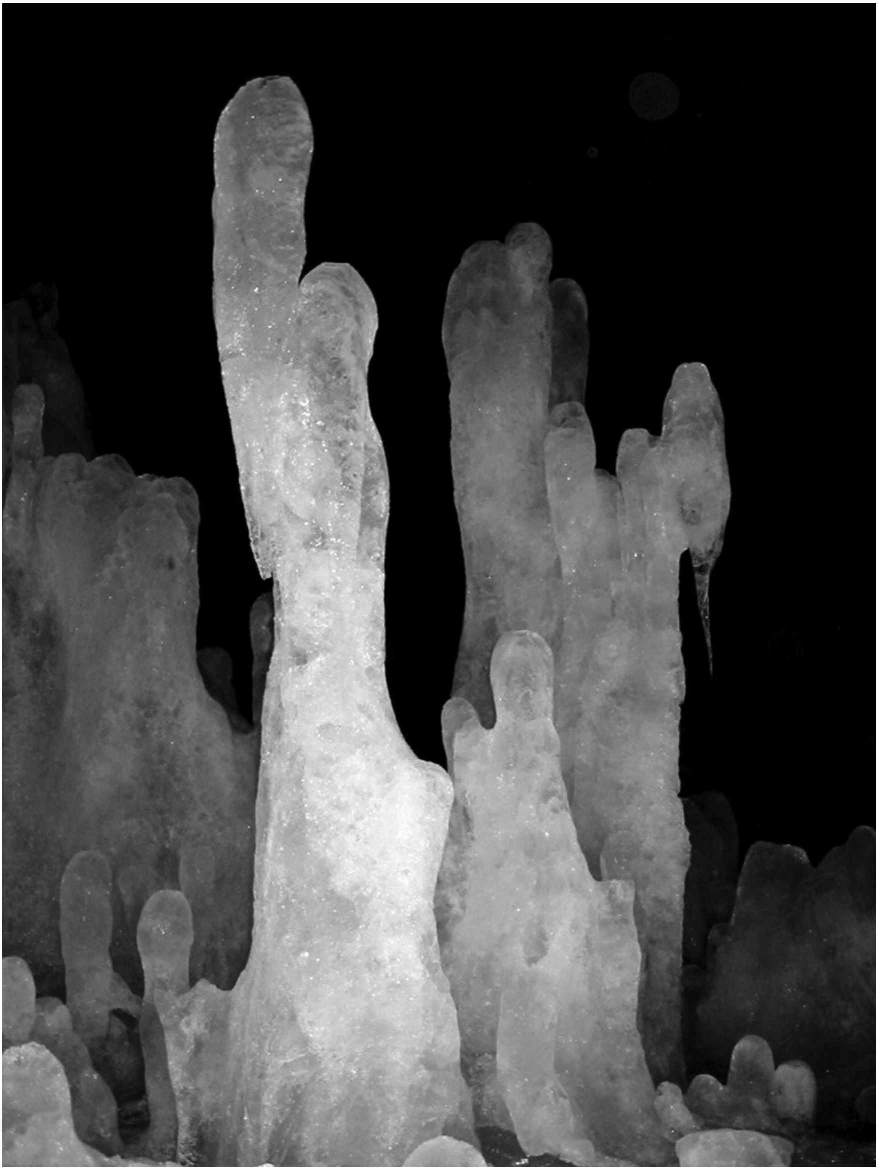

Plate 25 Formations inside Scarisoara's Ice Cave. Photo by Monica Exner

Plate 26 Stream flowing out of a cave opening, western Romania. Photo by Monica Exner

Plate 27 Interior of the Scarisoara Ice Cave. Photo by Monica Exner

Plate 28 Cave decorations in Ursilor Cave, Romania. Photo by Monica Exner

Plate 29 Formations in Ursilor Cave, Romania. Photo by Monica Exner

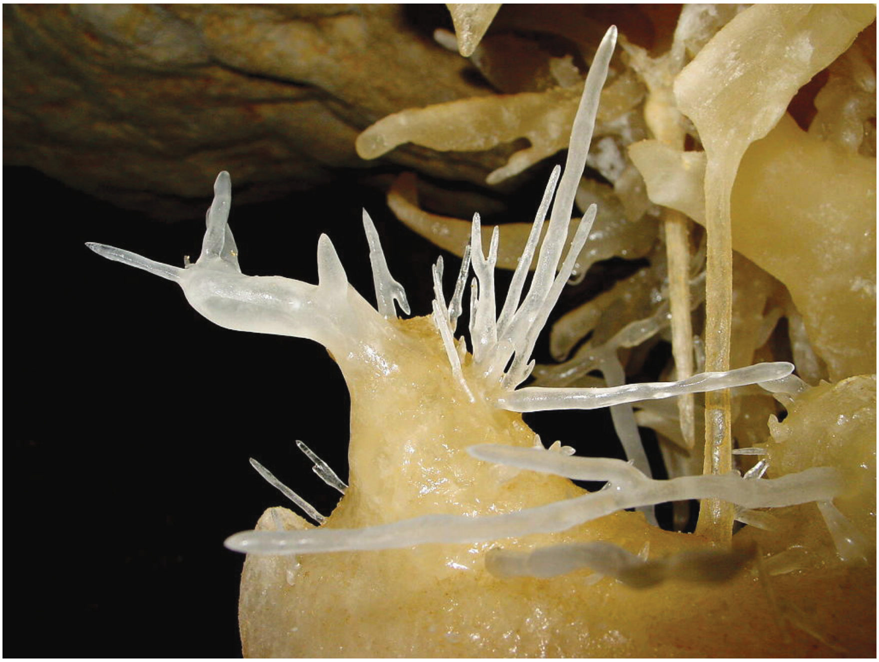

Plate 30 Helectites in Brooksville Ridge Cave, Hernando County, Florida. Photo by Tom Turner

Plate 31 Exploring Brooksville Ridge Cave. Photo by Tom Turner

Plate 32 Helectites, Brooksville Ridge Cave. Photo by Tom Turner

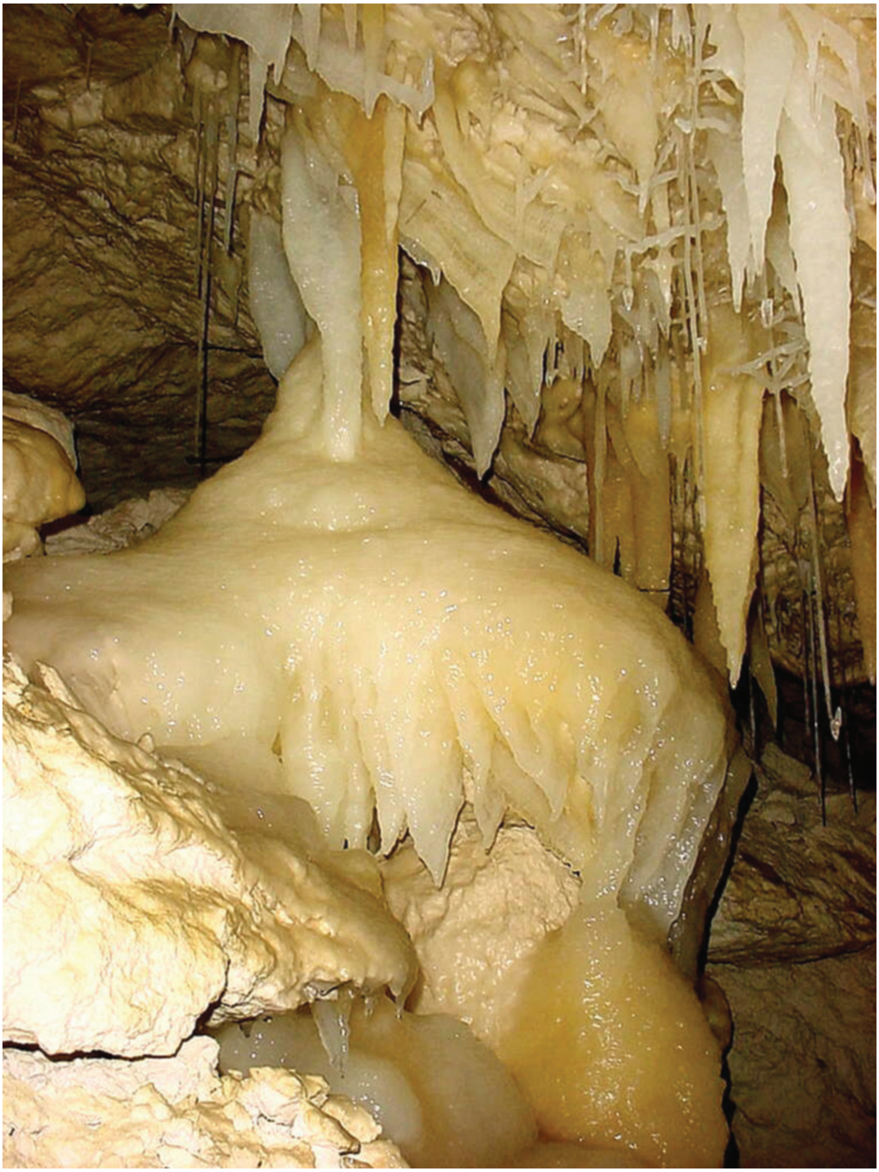

Plate 33 Calcite formations, Brooksville Ridge Cave. The moisture on the formations gives them the appearance of being made of ice. Photo by Tom Turner

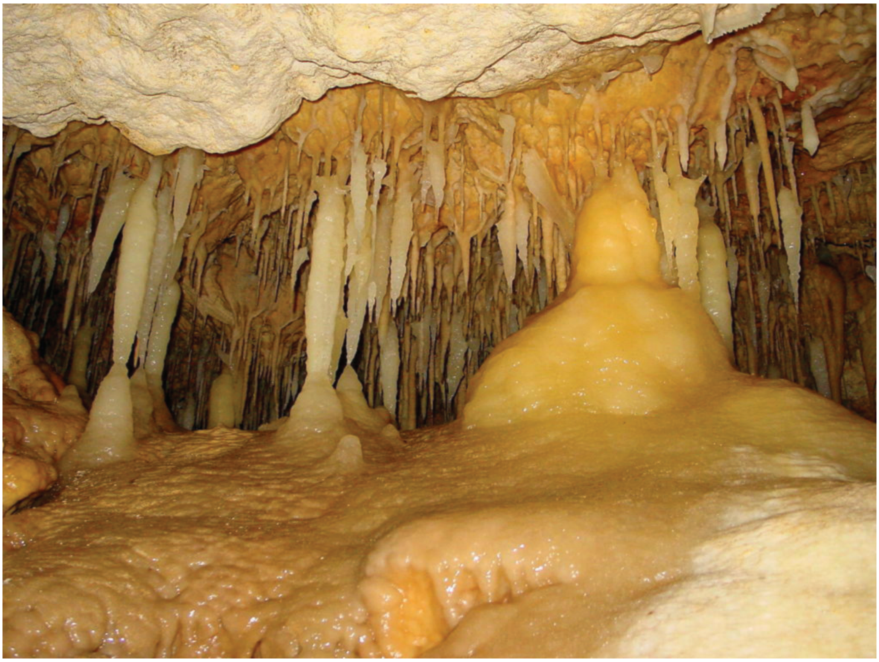

Plate 34 Various cave formations in Brooksville Ridge Cave. Photo by Tom Turner

Plate 35 Mapped karst points in the six counties of the Pennsylvania study area

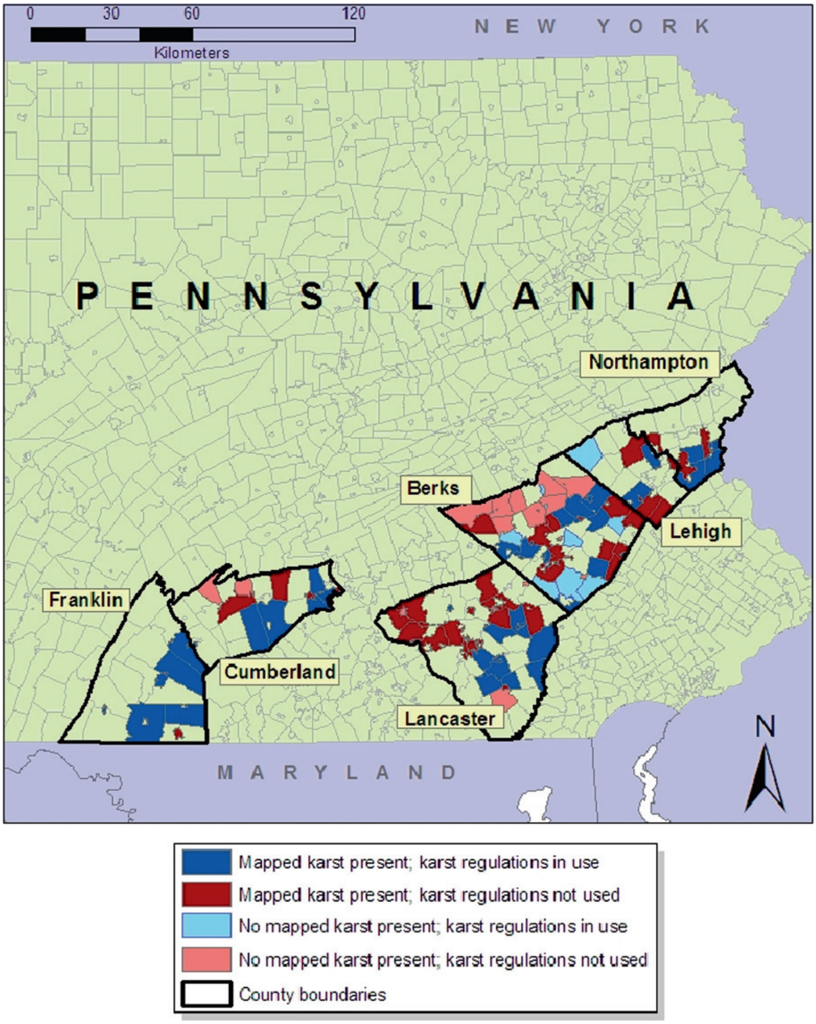

Plate 36 Distribution of karst and regulation practices in selected Pennsylvania municipalities

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