Chapter 15
Using Public Policy to Affect Human Behavior on Karst Landscapes in the United States

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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 sinkholes 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 provides an overview of karst-related land use regulation in the United States including commonly used techniques, geographic distribution of different regulatory approaches, and factors that tend to influence the regulation-writing process.

15.1 Introduction

Hundreds of years ago, in western Ireland, the local population sought fuel for its growing metal working industry. They found it in their abundant forests, but their aggressive approach to deforestation 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). During the twentieth century, southwestern China underwent an intensive process of industrialization. For decades, hundreds of factories there have produced noxious air pollution which has been 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 developed into a key part of the local economy. All this environmental stress over all these years was simply too much for the landscape 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 (Tihansky 1999). Both of these retention ponds were located directly above sinkholes; fortunately, in both cases the actual damage to the aquifer was manageable.

While each of these events occurred in different eras and different parts of the world, they share some common traits. 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 eighteenth 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 initially local people clearly understood the relationship between land use practices and local environmental health. Still, these incidents provide a stark lesson in the dangers of inappropriate land use practices in karst terrains and an example of the seriousness of the environmental consequences. Unfortunately, these are reoccurring problems. The goal of this chapter is to provide an overview of the issues of human-karst interaction, some of the most commonly used regulatory techniques involved in managing those issues, and the process that goes into developing those regulations. This is done with an eye toward developing a more standardized understanding of where karst land use regulations fit in the interaction process between human systems and karst systems.

This chapter focuses primarily on karst regulations in the United States. Many of the examples come from Florida and Pennsylvania. This is because both states have significant karst formations and employ myriad techniques to address the issues of human-karst interaction. It is hoped that this diversity provides the reader with a broad understanding of both the common issues in karst regulation and the regulatory toolbox planners and regulators have at their disposal.

15.2 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, generally through

inducing cave degradation, groundwater contamination, and land subsidence. In turn, these impacts often define how and to what extent humans can interact with the karst landscapes they occupy.

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? Many municipalities have taken an approach based in land use policy to protecting karst and regulating development in its vicinity.

15.3 Karst Land Use Regulation in the United States

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 – for example, the wide-ranging policy controls in place in Austin, Texas, are often cited as having had a major role in protecting the Edwards Aquifer – 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 bodies often have more narrowly focused areas of responsibility that make taking 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.

15.3.1 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 of flooding, surface and groundwater contamination, and sinkhole formation and collapse, municipalities certainly have an interest in enacting karst-related regulation. Differences in physical and social landscapes between individual cities and towns often influence the choice of regulatory techniques employed in each municipality. 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.

15.3.1.1 Zoning Ordinances

Generally speaking, zoning ordinances are implemented by both city and county governments; however, the exact division of responsibility for zoning varies from state to state. 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.

15.3.1.2 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.

15.3.1.3 Stormwater Management Ordinances

In a karst context, stormwater management ordinances often forbid directing or piping surface runoff straight 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; furthermore, 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.

15.3.1.4 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 is often 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.

15.3.1.5 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 plan recommendations and goals are usually not binding, which means they rarely 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, this chapter does not address their role or impact.

15.4 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, such as 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. 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 US Environmental Protection Agency (EPA); for example, all landfills must have a groundwater monitoring system in place in the immediate vicinity of landfills. 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).

15.5 Influences on the Design and Implementation of Karst-Related Land Use Regulations and Ordinances

Differences in karst regulations from one place to another are often the result of differences in the regulatory process and regulation-writing experience between those places. Each locality will face a different set of influences and inputs – or example, the level of stakeholder interest and input, or the physical characteristics

of the karst system itself – into the regulation process. With so many variables at work, uniformity is perhaps beyond hope.

The following discussion is limited to inputs that are either a significant factor in the process of writing and developing these regulations, or seem 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, existing research does indicate 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 below.

Technical expertise: Input from non-elected professionals like geologists and hydrologists has been cited as being a critical factor in the development of karst-related land use regulations (Fleury 2009). This is not surprising, as Sabatier and Jenkins-Smith (1988) emphasized the importance of specialist knowledge ("policy-oriented learning") in their Advocacy Coalition Framework of the policy process. The research suggests 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 (Fleury 2009).

Enforcement authority: Without the ability to enforce karst protections, stakeholders with an incentive (particularly, a financial incentive) to ignore regulations are very likely to do exactly that. Outside of a protected area context, both the existing literature and interviews suggest that enforcement authority is a factor in karst land use regulation in non-protected areas in the US (Fleury 2009). For example, a comprehensive plan that attempts to control growth in carbonate areas is not likely to be effective if a zoning ordinance to implement and enforce the priorities of the comprehensive plan is absent (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.

Nature and "framing" of the problem: 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 (Fleury 2009) 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 can die on the vine if it is 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. Fleury (2009) suggests 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. In the study conducted by Fleury (2009), 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 his/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.

Extent of the karst system: The size of the underlying karst system seems to play a role in determining the form of the karst-centric land use regulations that are ultimately implemented, but not on the restrictiveness of those regulations. According to Fleury (2009), 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.

"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. Fleury (2009) found, in follow-up interviews with planners and land use professionals, 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, research suggests that there is little reason to consider the mere existence of such regulations in neighboring towns as a factor in deciding whether to implement regulations focused on karst 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 lack of impact 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.

Attitudes of planners and land use professionals: The attitudes of land use professionals are critical in the process of crafting and implementing karst land use regulations (Fleury 2009). 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 in which land use regulations do not address karst-related issues are more likely to employ land use professionals who expect karst land use regulations 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.

15.6 Regulatory Impacts on Urban Systems and Human Settlements

There are two ways to assess the impacts of karst-related land use regulations. The first is through direct assessment of physical changes to the karst system itself, via water quality tests, or quantifiable measures of cave protection. The second is through observation of more indirect measures – these include settlement patterns, density, and economic considerations, among others. These metrics can be indicative of the ways in which local populations inhabit and use the landscape, which can change in response to the influence of karst-related land use regulations. This section focuses on these less direct methods of observing the impact of regulations in karst terrains.

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, Fleury (2009) demonstrated that 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 conducted by Fleury (2009), 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, Kentucky, 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, personal communication). 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 in Fleury (2009) as expected outcomes of implementing karst regulation. However, the same research indicates that these outcomes are not often observed. 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 (Fleury 2009).

Regulatory strength and restrictiveness: Most respondents to Fleury's 2009 survey 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. Restrictiveness was shown to have no impact on either median home values or on the number of residential construction permits issued (Fleury 2009).

Form of regulations: Survey results suggest that stormwater runoff regulations are the easiest type of karst-related land use regulation to push through local political infrastructures. 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. 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, or the most common, in Pennsylvania local land use regulation (Fleury 2009).

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 personal communication).

Interviews with those in the professional planning community 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.

15.7 Conclusions

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 (e.g., groundwater supplies or tourist attractions) that they provide. There is no single, unified approach to the implementation of this type of regulation. The variety we see in the nature and structure of karst-related regulations between towns 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. The patchwork, individualized nature of karst regulations, and ordinances at the local level makes it difficult to generalize; what works in one place might not in another. However, we can draw some useful conclusions from the preceding pages. First is that less obtrusive karst regulation has the best chance of implementation, particularly if a connection can be made to a separate, more visible issue like stormwater runoff. This is because the low level of karst knowledge in the general population makes it much harder to pass more specific, restrictive karst-related regulations.

Second, karst regulations that are presented as protections for residents and their homes and roads *against* karst landforms like sinkholes may fare better than regulations that are framed as environmental protections. This is because, in the policy-making arena, fear can be an effective motivator; certainly, the idea of losing one's home to an unstoppable, expanding sinkhole would be a higher concern for most people than the idea that an unseen ecosystem might suffer irreparable damage. Regulations intended to address water quality issues can also be presented in this way, as a means to protect residents from nature's threats.

This is not intended to suggest that deception should be employed when seeking to pass karst-related land use regulations. Instead, scientists, planners, and land use professionals are urged to keep in mind that the general public often does not share their understanding or concern regarding the threats posed by human activities to local karst systems. We should, whenever possible, bear this in mind when seeking to protect karst systems from human activities via the regulatory process.

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