5-2014

Local Regulatory Protection for Ecosystem Services: A Case Study from the Karst Region of Southeast Minnesota, USA

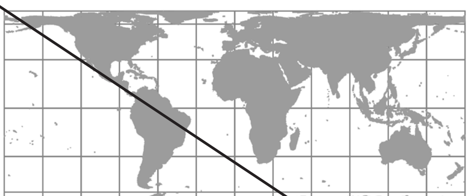
Mary A. Williams

Susy Ziegler
Northern Michigan University

Local Regulatory Protection for Ecosystem Services: A Case Study from the Karst Region of Southeast Minnesota, USA

Mary A. Williams
College of Biological Sciences
University of Minnesota
St. Paul, MN 55108
E-mail: williams@umn.edu

Susy Svatek Ziegler
Department of Earth, Environmental, and Geographical Sciences
Northern Michigan University
Marquette, MI 49855-5301
E-mail: suziegle@nmu.edu



The Geographical Bulletin 54: ??-??

ABSTRACT

Human communities depend upon a myriad of ecosystem goods and services, which are produced by and depend on natural environmental processes occurring at multiple temporal and spatial scales. Land-use policy seldom recognizes the importance of these services or the environmental processes generating these services. This study examined the degree to which ecosystem services and supporting environmental processes are regulated at two United States municipal levels: city and county. Several ecosystem services but few environmental processes are regulated to some extent. We identified policy needs for environmentally sensitive karst features, aquifer recharge, groundwater quality, plant and animal populations, and flood mitigation. We propose policy instruments that could help sustain regional ecosystem goods and services and conclude with planning ideas to cover these gaps, including measures from other karst regions that could support and enhance sustainable land planning and policy development.

Key Words: ecosystem services, land-use policy, karst, landscape functions, Minnesota

INTRODUCTION

Widespread changes of Earth's ecosystems are evident in the global transformation of land areas associated with human activities. These alterations to ecosystems modify the ecosystem goods and services that sustain human communities, along with the associated landscape functions that produce these services. Although some research demonstrates the dependence of human welfare on a variety of ecosystem services (Daily 2000, Boyd and Wainger 2002, Diaz et al. 2006, Fiedler et al. 2008), fewer studies examine the steps that policymakers have taken or need to take to regulate human behavior and thus protect these goods and services. Protection of ecosystem goods and services via policy is critical because regulations are de-facto land management strategies that impact ecosystem services even if the policy linking land use and ecosystem services is only implied.

We define ecosystem services as those goods and services produced by a landscape or ecosystem that contribute directly to human well-being (Daily 1997). To recognize an ecosystem good or service is to acknowledge that a natural landscape or ecosystem function produced a free good or service that is directly consumed by human communities or provides for their well-being. Landscape or ecosystem functions directly result from one or more naturally occurring physical actions (e.g. water infiltration) and/or land surface conditions (e.g. percent pervious surface). Such functions can exist in the absence of humans and are part of the natural properties of ecosystems and landscapes. The term *land use* is defined as how humans modify, manage, and benefit from a specific expanse of ground surface. Land-use activities modify the biophysical attributes of land cover for perceived human benefits.

The production of ecosystem functions and services has been compromised by an increasingly urbanized society with dense settlements and large areas of cleared land. Land-use policy shapes urban development and can mandate infrastructure that supports or reduces urban ecosystem services (Bolund and Hunhammer 1999; Ruhl et al. 2007, Niemela et al. 2010, Jenerette et al. 2011). Layers of social inequality can exacerbate local and regional ecosystem service production (Tratalos et al. 2007, Jenerette et al. 2011). Land-use policy should strive to maintain sustainable provisions of ecosystem services and to keep these services away from critical thresholds that could result in their degradation or loss.

A few stakeholder efforts are underway to promote the incorporation of broader-scale environmental processes into local and regional land planning, (Theobald et al. 2005, Miller et al. 2008, WGA 2011). Various methods for ecological management in human settlements using various bio-physical (e.g. watersheds) and ecological (e.g. ecosystem-based management) principles have been recommended by environmental scientists (Aspinall and Pearson 2000, Bacic et al. 2006,) and planners (Grant et al. 1996, Beatley 2000, Gober 2010, Quay 2010), but most efforts address ecosystem goods and services only indirectly. Urban systems, however, are dynamic with many interrelated components and must be addressed through integrative and adaptive environmental management rather than specific land-use policy that narrowly focuses on singular environmental issues.

Explicit regulatory consideration of the impact of land-use activities on ecosystem services is particularly important in regions where most land-use decisions are made at local governing levels. Land development at the local level affects and is affected by the broader biophysical environment (Dale et al. 2000, Beatley 2000, Selman 2002, Tscharntke et al. 2005, Fiedler et al. 2008). Standards and codes are often copied from distant municipalities (Ben-Joseph 2004), which can cause environmental and economic problems, particularly when applied to regions with different physical geography.

In the United States (U.S.), a few municipalities have implemented policies that explicitly protect local and regional ecosystem goods and services. New York City, for example, chose to restore and conserve the Catskills Mountain watershed to produce quality drinking water. Although research has progressed regarding the social and economic needs for ecosystem goods and services (Viglizzo et al. 2011, Bateman et al. 2013), policy development for the protection and long-term sustainability of these services has lagged behind (Daily et al. 2009).

This case study assesses the degree to which local policymakers have incorporated the protection of ecosystem services and supporting landscape functions into municipal policy. We identified apparent gaps in coverage, discussed ways to cover these gaps, and presented additional policies and landscape planning methods that could support and enhance current policy and sustainable land planning for these and similar municipalities. We sought to examine the current regulatory state to determine how well locally and regionally produced ecosystem goods and services are protected. Our overarching goal was to facilitate both discussion and action for improved environmental management.

CASE STUDY BACKGROUND

Our study area of Wabasha County is located in southeast Minnesota, U.S. (Fig. 1). This region has scenic blufflands created by the Mississippi River and its tributaries, multiple river valley plateaus, karst landforms, and a variety of ecosystems including oak savannas, floodplain forests, shrub wetlands, open wetlands, and prairies. Natural resource inventories revealed that this region, comprising only three percent of Minnesota's total area, contains habitat for 43 percent of Minnesota's plant and animal species listed as endangered, threatened, or of special concern (McCormick 2007).

Wabasha County is governed by five county commissioners coordinated by a county administrator. This county has a published comprehensive land-use plan and has established zoning ordinances for all county land areas that are not on city land. Counties in Minnesota have no legal land-use authority in city boundaries, except when requested by a city (Association of Minnesota Counties 2002a). Under state law, Minnesota county commissions plan county land-use (Association of Minnesota Counties 2002b). The Wabasha County Commission makes all final decisions on land-use activities in the county for areas outside of city boundaries.

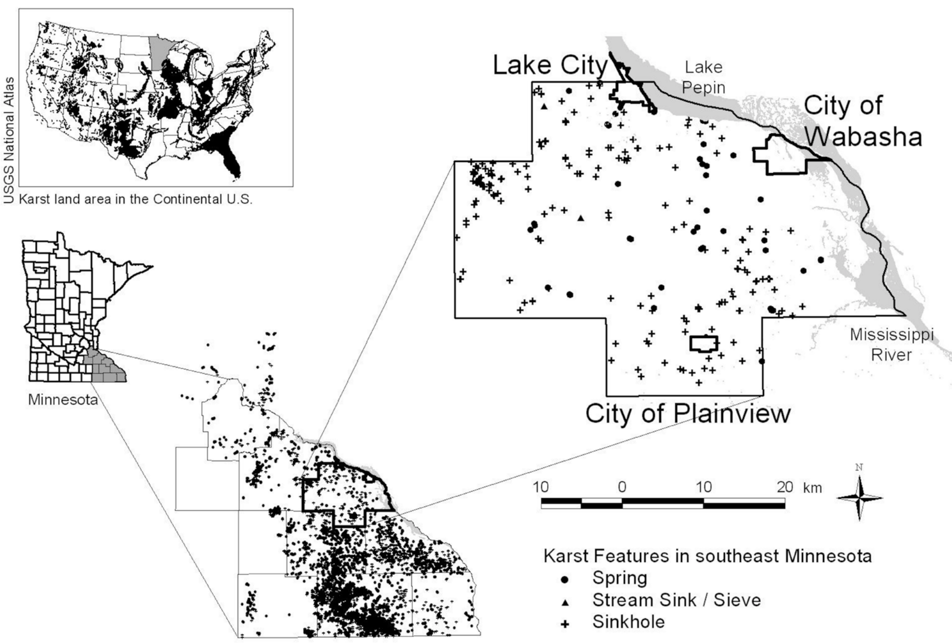


Figure 1. In southeast Minnesota, USA, more than 10,000 karst features have been located, georeferenced, and included in a geographic information database created and maintained by the Minnesota Geological Survey (Gao *et al.* 2002). Wabasha County, located in southeast Minnesota, has more than 20,000 people in 10 incorporated cities and two unincorporated villages.

Through zoning ordinances, Minnesota counties and cities have complete control over land-use activities except for minimum state-required regulations for shore lands, floodplains, sewage treatment systems, and building codes. Local municipalities are allowed to pass regulations stricter than any federal or state regulations.

Minnesota state law requires city governments to regulate certain activities including: the use of streets and other public grounds, planting and protection of vegetation on city property, and zoning and land-use controls (Handbook for Minnesota Cities 2007). Cities are not required to get voter approval to enact any ordinance. Each city council makes all final decisions on land-use activities in its respective city.

This study area is characterized by karst topography. The term "karst" describes predominately limestone and dolomite landscapes primarily weathered through a chemical dissolution process. Over geologic time, karst features such as sinkholes, bedrock springs, fractures, sinking streams, and caves form on and under the land surface promoting fast subsurface infiltration of surface waters and any associated pollution. Karst features are either surficial (e.g. springs or sinkholes) and thus easy to see, or subsurface (e.g. caves). Knowledge about subsurface karst features is impossible without a surficial expression (like an entrance to a cave), and understanding karst hydrogeologic interconnections is challenging even for seasoned hydrogeologists.

An estimated 20 percent (White 1988) of the earth's land surface is karst, and in the United States, approximately 25 percent of land is karst (USGS 2010). Land in karst regions is typically unstable. Construction projects on karst landforms can have various deleterious environmental and economic impacts including failure of foundation and slab, pipes and buried utilities, impoundments and liner systems, and roadways (Beck 1995, Ralston et al. 1999). Environmental concerns include flooding (Zhou 2007) and water degradation (Mahler and Lynch 1999, Wicks et al. 2004, Davis et al. 2005).

Because of historical problems with development on karst landscapes, published regulatory reviews reveal evolving guidelines for policy development that incorporate references to and protection of karst in various karst communities in the United States (see review by LaMoreaux et al. 1997). Despite this legal recognition of karst sensitivities from some municipalities, however, many karst regions remain legally unprotected from potentially deleterious land development activities.

In southeastern Minnesota, more than 10,000 karst features have been located, georeferenced, and included in a geographic information database created and maintained by the Minnesota Geological Survey (MGS) (Gao et al. 2002). In addition to understanding the spatial layout of the karst features, this information can aid in finding and protecting natural resources that are unique to karst regions and important for the provisioning of landscape functions (e.g. biodiversity) and ecosystem services (e.g. clean drinking water, cultural resources and tourism) found in these areas. Without knowledge of what resources exists in terms of karst-specific natural resources, then policy decisions will not be informed decisions. For example, although some research has highlighted the varieties of obligate karst biota found in the United States, including a high number of threatened or endangered species (Culver et al. 2000, Elliot 2000), little published work describes cave biota of Minnesota. We located only one scientific study listing eleven species of troglophiles, two species of troglobites, and two species of trogloxenes living in caves in Wabasha and Fillmore counties in southeastern Minnesota (Peck and Christiansen 1990). Given this and other findings of new cave species in other karst regions of the United States (e.g. Christiansen and Bellinger 1996a, Christiansen and Bellinger 1996b, Lewis et al. 2003), the possibility of learning new information about local and regional natural resources is high. Expanding settlements and land development could, however, deprive the region of unique natural resources and could reduce the regional levels of biodiversity before they can be thoroughly investigated.

From this area, we selected Wabasha County and three cities within this county for this study because they are located on karst, their municipal ordinances were freely available for download over the Internet, and they represented a range of regional urban, exurban, and rural communities (Table 1). Environmental stakeholders that help manage resources in this region include The Nature Conservancy, the MGS, the U.S. Army Corps of Engineers, and The Upper Mississippi River National Wildlife and Fish Refuge. Wabasha County encompasses or shares a boundary with land owned by each of these organizations. Across Wabasha County, 200 sinkholes, forty-five springs, and two stream sinks have been georeferenced and entered into the MGS karst database (Fig. 1). Further complicating land management activities, several extensive subsurface cave systems have also been mapped in this county (Tipping 2002).

Table 1. County and city regulatory and demographic characteristics.

Demographic or Land Cover Characteristic	City of Wabasha	City of Plainview	Lake City[3]	Wabasha County
Regulatory Structure	Mayor, six Council Members	Mayor, four Council Members	Mayor, six Council Members	Five Commissioners
Population[1]	2,559	3,190	4,950	21,610
Population density (per mi^2)	318	1,453	1,169	41
Number of housing units	1,166	1,223	2,347	9,066
House unit density (per mi^2)	143	557	553	17
Municipal engineer	No[4]	No[4]	No[4]	Yes
Land cover[2] – Total (mi^2)	9.25	2.20	4.30	549.00
Deciduous forest	3.24	0.02	1.15	139.03
Exposed soil; sand dunes	0.01	0.00	0.00	0.19
Grassland	0.29	0.04	0.35	71.77
Grassland–shrub–tree	0.06	0.00	0.03	1.03
Gravel pits; open mines	0.15	0.00	0.03	0.52
Rural	2.31	1.10	0.82	304.69
Urban and industrial	2.13	0.92	2.01	5.65
Unclassified	0.00	0.00	0.00	0.08
Water	1.04	0.01	0.04	24.15
Wetlands	0.01	0.00	0.00	2.03

[1]All data except for land cover data are from 2000 Census.

[2]Land cover data are from 1990 International Coalition Land Use/Land Cover GIS dataset. Total of individual land areas does not equal the stated total due to rounding.

[3]Includes the portion of the city in Goodhue County.

[4]Not identified in municipal records. However, the public works director is often a certified engineer and serves in the capacity as the municipal engineer.

Most of the drinking water in Wabasha County comes from wells drilled into nine subsurface karst aquifers. Two specific groundwater systems are recognized in the county: the upland area system and the river valley system. The majority of the rural residents living in Wabasha County have their wells in the upland areas of the county in a region of groundwater recharge (Fig. 2). The river valley system is a major area of groundwater discharge, but most land in Wabasha County is upland area that supports aquifer recharge. The susceptibility of groundwater to pollution from land-use activities has been rated high to very high over most of this area (Peterson 2005). Protection of fresh water presumably is an important goal in southeastern Minnesota. Delineation of groundwater resources is an important step towards this protection.

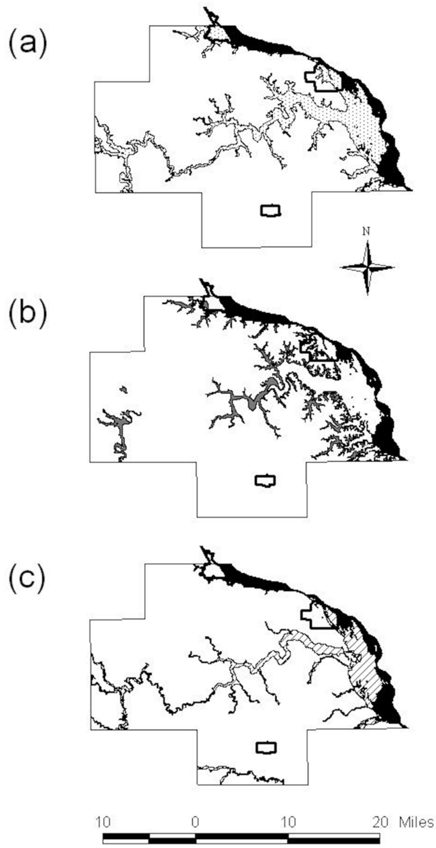


Figure 2. Wabasha County, with the Mississippi River (in black) forming the eastern county boundary, and its (a) upland recharge areas (in white) and river valley discharge areas (speckled shading), (b) St. Lawrence recharge region (gray shading) where surface water travels quickly to aquifer systems, and (c) floodplain management areas (shaded with diagonal lines). The three cities of the study are heavily outlined in black.

METHODS

For an environmentally sensitive karst region in southeast Minnesota, we evaluated policy for coverage of ecosystem services, landscape functions and locally known karst features. We asked three questions regarding the extent of their regulatory protection: (1) Was the karst feature, landscape function or ecosystem service directly or indirectly protected by any of the city or county ordinances?; (2) How is this feature, function or service tied to the karst nature of the landscape?; and (3) Could an ordinance from elsewhere serve as a better ordinance in this study area? We identified and discussed ways to cover gaps, and presented additional methods that could enhance sustainable land planning for these and similar municipalities.

Although a few studies have discussed the need to develop local policy measures to better protect specific environmental processes (e.g. Woolf and Sommer 2004, Lankao 2007), we have explained how our proposed policies would complement existing policies. We neither state nor infer that the county or city ordinances were the only policies that determine land use in this particular area. An in-depth discussion of the full range of land-use policy from local to federal levels is beyond the scope of this paper. Understanding the *local* state of ecosystem service regulation, however, increases our understanding of the needs and challenges of this critical human–environment connection, providing a springboard for discussion and subsequent evolution of sustainable environmental management. This type of analysis can be repeated in any politically delineated unit and could be especially useful in environmentally sensitive regions.

We evaluated municipal policies for Wabasha County and three cities within this county in southeast Minnesota. We downloaded and assessed each ordinance published on the respective governmental websites for specific references to a list of landscape functions and ecosystem services (Table 2). We recorded any ordinance that specifies either the existence of, need for, maintenance of, or protection of a landscape function or ecosystem service found on our list, consistently recording the ordinance numbers to allow reference back to the specific ordinance. For example, City of Wabasha ordinance 335.37(1;17) states that "When possible, existing natural drainage ways, wetlands, and vegetated soil surfaces must be used to convey, store, filter, and retain storm-water runoff before discharge to public waters." This ordinance was recorded as explicitly recognizing the existence of and need for natural drainage and filtration, even though it falls short of regulating the protection of these services.

To maintain consistency through the policy analyses, only one person analyzed the policy language. For each landscape function and ecosystem service, she recorded only those ordinances that explicitly referenced the specific function or service. These data were recorded into a table, separated by municipality (Ziegler and Williams 2008). Evaluating these types of links between policy and natural environmental processes will help uncover disparities and strengthen the relationships that must exist for the overall sustainability of both human communities and the natural resources upon which they depend.

RESULTS AND DISCUSSION

Karst Features and Natural Landscape Functions

Two categories of karst land-planning and ordinance legislation have been proposed: storm-water management ordinances and land-development control ordinances, both of which control land-use decisions on individual parcels of land (Ralston and Oweis 1999). All municipalities in this study contain these two types of ordinances, but none explicitly referenced karst or karst features. The Wabasha County comprehensive land-use plan stated that, "Wabasha County is located in a Karst topography region," but otherwise did not directly address the sensitivities of karst. As the single municipal ordinance that referenced a karst feature, Wabasha County zoning ordinance Article 5 stated that, "No new feedlot shall be within 300 feet of any sinkhole." No other comprehensive land-use plan or ordinance in any of these municipalities directly referenced karst landscapes. This lack of regulatory coverage for karst features is problematic because land development in karst often creates or exacerbates regional socioeconomic and environmental problems by inducing sinkhole development, modifying storm-water runoff and vegetation cover, generating water-table drawdowns, and adding point- and non-point-source pollution (e.g. White et al. 1986, Neill et al. 2004, Alexander et al. 2005).

In response to problems associated with the lack of and need for regulatory coverage of karst features, several municipalities elsewhere have modified or developed ordinances and land-use plans to incorporate the definition of karst. For example, the Monroe County, Illinois, Comprehensive Development Plan, as part of its Comprehensive Land Plan, has an entire section on karst topography and a map that identifies the location of sinkhole plain areas (Bade and Moss 1999). As one method for recognizing karst features in their ordinances, Monroe County officials added a definition

Table 2. Partial listing of regional landscape functions and ecosystem services that formed the base of this policy analysis.

Landscape / Ecosystem Functions	Associated Natural Resources
Aquifer discharge/recharge	Plant communities; soils; water
Climate interactions	Biotic and abiotic land features
Erosion control	Plant communities; soils
Flood mitigation	Wetlands; soils; streams
Nutrient cycling	Plant communities; soils; water; wetlands
Provision of aquatic habitat	Abiotic land features; riparian communities; streams; water; wetlands
Provision of plant habitat	Soils; upland, riparian, wetland communities; water
Provision of wildlife habitat	Upland,riparian,wetland communities;wildlife
Soil formation	Biotic and abiotic land features
Storm-water management	Plant communities; soils; streams; wetlands
Water temp moderation	Land features; riparian communities; water
Water filtration	Upland, riparian, wetland communities; soils

Ecosystem Goods and Services	Provisions to Human Communities[1]
Biodiversity	Fishing; hunting; birding; education
Bird populations	Birding; public health; education
Clean air	Public health
Clean groundwater	Drinking water; crop irrigation
Clean surface water	Drinking water; swimming areas
Fish populations	Food; fishing; public health; education
Flood mitigation	Risk reduction; public health
Game populations	Food; hunting; public health
Natural ecosystems / viewsheds	Cultural values; education; fishing fuel; hunting; public health
Pollinator populations	Pollination services for human crops
Shelter and shade	Air conditioning; physical health
Soil quality	Growth medium for human crops
Storm-water management	Water management; public health
Surface water bodies	Education; fishing; swimming; skiing
Timber	Timber products for human use
Waste assimilation	Animal waste disposal/composting; soil development

[1]All ecosystem goods and services support economic activities. Positive or negative impacts to these goods and services will have the respective impacts on the local or regional economies (Millennium Ecosystem Assessment 2005).

for "sinkhole" for every ordinance, and then modified the Monroe County Subdivision Ordinance and Public Health Private Sewage Disposal Licensing Act and Code to improve safeguards against pollutant discharge into any known karst feature.

These evolving regulatory recognitions of karst influence, labeled "limestone ordinances" (Fischer 1999), while recognizing the inherent complexities of karst, simply regulate certain construction activities in the immediate vicinity of known surficial karst features (Table 3). However, parcel-level regulations do not recognize or protect the larger-scale interconnected hydrological processes found in karst landscapes. An example of karst ordinances on a larger watershed scale is that the Texas Edwards Underground Water District and regional water management districts in Florida view their associated karst systems on aquifer-wide spatial scales and regulate activities with an eye on pollution prevention and long-term water quantity conservation (LaMoreaux et al. 1997). Evaluated over a larger land area, policy instruments could protect sensitive land areas while permitting heavier development where it will interfere less with important environmental functions.

None of the reviewed ordinances regulated the maintenance or protection of aquifer

Table 3. Existing and proposed karst land-use policies, termed "limestone ordinances," in the United States[1].

Parcel-scale development activities
Prohibit the dumping of trash into sinkholes[1]
Compensate developers who lose portions of land due to sensitive karst features[1]
Allow non-developable karst areas like sinkholes to be set aside for open space, parks or green belts (as safety allows)[1]
Allow higher density residential buildings for lands which lose area due to karst sensitivities[1]
Prohibit development on any property with waste deposits in sinkholes[2]
Define elevation segments of sinkholes, sinkhole divides and immediate sinkhole drainage area[2]
Size subsurface seepage systems installed in a karst soil based on the results of an on-site soil investigation[2]
No private sewage disposal systems or components permitted within the lower elevation segments of sinkholes[2]
Prohibit surface discharges within 50 feet of an immediate sinkhole drainage area[2]
Prohibit surface discharge systems in sinkhole plain areas (areas where all of the surface drainage leads to the subsurface)[2]
Prohibit subsurface seepage fields within 75 feet of the point where the slope of a sinkhole side exceeds 5%[2]
Prohibit infill of sinkholes and limit development outside of specific sinkhole boundaries[2]
Prohibit discharge of storm water into sinkholes[2,3]
Landscape-scale development activities
Define, delineate and avoid development around sinkholes, sinkhole drainage areas and potential sinkhole cluster areas[1,2]
Define "Karst Overlay Zoning Districts" and prohibit development in hydrogeologically- or biologically-sensitive land areas[3]
Mandate incorporation of springshed boundaries and preservation of karst hydrogeologic functions[3]
Mandate public education efforts about sustainability of karst features, natural landscape functions and ecosystem services[3]

[1]Adapted from Ziegler and Williams (2008) with permission

[2]Dinger and Rebmann (1986)

[3]Fischer (1999)

recharge. Several ordinances indirectly addressed this function through efforts to control the percentage of impervious land surface on development parcels. Broward County, located over a karst aquifer in south Florida (Manda and Gross 2006), adopted a larger scale view of land planning when it developed “Drainage and Natural Aquifer Groundwater Recharge” guidelines for storm-water management activities. These activities in part “promote recharge to the Biscayne Aquifer” based on storm-water management guidelines over watershed scales (Broward County 2006). Although these guidelines are directed at parcel-level activities, the overarching purpose and goal incorporates a larger scale view of land processes for the long-term sustainability of regionally recognized natural resources.

The natural development and maintenance of plant communities and wildlife habitat is an important landscape function, especially in complex, spatially heterogeneous landscapes (Pastor 2005). Karst adds to this complexity through its impacts on regional ecohydrological processes affecting the development of plant and animal populations (e.g. Furley and Newey 1979, Culver et al. 2000, Fetterman et al. 2003, Kobza et al. 2004). Several ordinances indirectly addressed the natural development and maintenance of plant communities and wildlife habitat by requiring the preservation or restoration of natural vegetation to the greatest extent possible during development projects (e.g. Wabasha County ordinance A6S6(5;5)ZO and Lake City ordinance A6S7(A;3)). Decisions, however, are made on a parcel basis and generally cover engineering or construction issues (e.g. screening or erosion control). No ordinances mandated management, protection or connectivity of plant communities, ecosystems or wildlife habitats. Caves, for example, are known habitat for a variety of fauna and at least twenty-two states have passed cave protection acts (Huppert 1995, LaMoreaux et al. 1997), but neither Minnesota nor any of its county or local municipalities has followed suit. The city of Austin, Texas, in contrast, developed watershed regulations with incorporated language that protects groundwater, caves, and associated biota (Austin City Connection 2010).

Ecosystem Services

In this karst region, the land surface is directly connected to groundwater (Tipping 2002), and many ecosystem goods and services depend directly on the regional hydrogeology. Drinking water, for example, comes primarily from karst aquifers. Municipalities in this study acknowledged the need to protect the quality of this ecosystem good through ordinances developed to reduce or prevent pollution to both surface and groundwater. The City of Plainview, for example, had a written wellhead protection plan to guide land use and development projects around sensitive wellheads and recharge areas. The goal of this plan was to reduce or prevent pollution from entering the city’s source of drinking water. The other cities and the county had few mandated pollution prevention ordinances. An alternative storm-water management practice of using the natural land area to service municipal storm-water runoff to mitigate pollution was written in many ordinances. This written alternative is a direct recognition of the ecosystem service of water filtration.

We identified regulations that attempted to protect groundwater quality but none that targeted groundwater quantity. Surface and groundwater supplies are directly connected in karst systems, so water quality and quantity should be managed concurrently so that protection of one is not negated through neglect of the other (Veni 1999, Bonacci et al. 2008). When not managed concurrently, protective efforts for one can be negated through neglect of the other. For example, caves and sinkholes might be sufficiently protected to maintain aquifer recharge and water quality, but land-use activities a short distance away could contaminate the same aquifers. The water-related ordinances we found were directed at construction activities to reduce pollution discharges to water bodies. We did not locate any ordinances that mentioned the need to protect karst features that direct run-off to groundwater aquifers. In contrast, the state of Washington has developed a "Critical Aquifer Recharge Area" ordinance with the goal of "providing local governments with a mechanism to protect the functions and values of a community's drinking water by preventing pollution and maintaining supply" (Washington State 2010). King County, Washington, subsequently developed a "Critical Areas Ordinance as applied to Urban Properties in Unincorporated King County." This ordinance restricts land-use activities in those areas of land that pose risk to aquifer water levels and aquifer water quality, and Wabasha County could benefit from similar protection. Delineation of groundwater resources is important but needs to be followed by regulatory protection to sustain production of critical ecosystem services.

An ecosystem service acknowledged in each of the four comprehensive land-use plans was the protection of wildlife populations that contribute directly to personal, cultural, and socioeconomic well-being. In southeastern Minnesota, cold groundwater springs contribute to viable cold-water trout habitat and subsequently to a profitable fishing industry (Thorn et al. 1997, Hart 2008). The juxtaposition of a cold-water spring to a stream strongly influences the ecosystem service of the provision of cold-water fish species for human consumption. A great diversity of natural wildlife processes (e.g. herbivory, pollination, migration) interact in complex ways to provide many ecosystem services to human communities (Daily 1997). Multiple ordinances referenced the need to provide wildlife habitat although none were found to mandate protection for specific animals or populations. Only Wabasha County and the City of Wabasha explicitly listed a function of wetlands as providing "fish and wildlife habitat." Lake City ordinance A7S7(B4c;7) stated that golf courses shall be designed with consideration of the "use of landscaping and site layout to preserve and enhance wildlife habitat." This ordinance indirectly acknowledged that wildlife populations are important ecosystem goods in this region. In contrast, the City of Tampa, Florida, has developed an "Upland Habitat" ordinance that seeks to protect remaining upland xeric and mesic habitats in the city limits of Tampa that "constitute significant wildlife habitat, necessary to retain remaining habitat diversity and wildlife corridors and to maintain healthy and diverse populations of wildlife" (Municipal Code Online Library 2008).

Flood mitigation is another important ecosystem service because flooding can exacerbate water pollution problems, induce sinkholes, and cause damage to residential, commercial, and public properties (Kemmerly 1993, Halihan et al. 1998, Zhou 2007). Costs associated with these damages are borne by citizens and businesses. These costs can unexpectedly balloon with litigation (for an overview of examples of karst sinkhole litigation cases, see Quinlan 1986). Wabasha County and the City of Wabasha listed the function of wetlands for "storage of surface runoff to prevent or reduce flood damage", providing the ecosystem service of natural flood mitigation for county residents. Less than half of one percent of the land area in Wabasha County consists of wetlands, however, so this protection of wetlands would provide little natural flood mitigation for residents. To recognize floodplain hazard areas, Wabasha County established Article 14 "Floodplain Management Regulations", which acknowledged that flooding in this area can result in potential loss of life and property. This ordinance established guidelines for minimum elevations within an established floodplain overlay district. A variety of conditional uses and variances are allowed. Lake City and the City of Wabasha had similar published floodplain management ordinances. We did not find any existing ordinances that protected floodplains by prohibiting development in floodplains or by restricting floodplain use to light, low-impact land use (e.g. hiking, biking, hunting, greenways, open space). Maintaining floodplains in their natural and unfragmented state allows these landscapes to fulfill their functions of storm or flood-water storage, aquatic ecosystem provision and maintenance, water filtration, and maintenance of water quality as water travels through the landscape then downstream through multiple watersheds and human communities.

Land-Use Planning versus Land*scape* Planning

In this study, all municipalities acknowledged or addressed at least one landscape function and ecosystem service through policy instruments, most often through zoning policy directed at parcel scale, land-use activities. This finding is important because most local land planning and land-use policy emphasizes engineering or construction-related activities to address one or few environmental issues. This approach is not in line with current knowledge about larger scale environmental functions and services. Sustainable land*scape* planning will require that planners and policymakers view land use and community development more broadly over various spatial and temporal scales. To incorporate extraterritorial areas in land and watershed management, planners and policymakers could use various tools like geographic information systems and remote sensing to examine their larger physical environment (Lathrop and Bognar 1998, Stoorvogel and Antle 2001, Bacic et al. 2006). Assessments of ecosystem services could provide a baseline inventory for monitoring changes over time (e.g. Guo et al. 2000, Shelton et al. 2001). Incorporating non-traditional development projects can promote sustainable residential neighborhoods (Milder et al. 2008). Outreach from scientific communities can provide environmental education and guidance for land managers and policymakers (Brown and Kockelman 1996, Dale et al. 2000).

Active collaborations with regional stakeholders like neighboring municipalities, and federal, state, watershed or non-profit organizations could highlight regional environmental issues and reveal information supporting sustainable land planning and decision-making (Beatley 2000, Bacic et al. 2006). Implementation mechanisms to address ecosystem services and landscape functions could include such actions as direct management of sensitive land projects, provision of financial incentives to land managers, policy creation for preservation or restoration of environmentally sensitive lands, adaptive modifications of land-use policy to incorporate advances in science and technology, provision of information and monitoring to support specific services and functions and educate the public, and the initiation of workshops to facilitate collaboration and exchange information among regional stakeholders. In turn, ecologists and other scientists can increase their participation in land planning and policy development (Clark 1992).

CONCLUSIONS

Land-use policy and land-use activities can be evaluated on local and regional scales to assess how effectively they protect natural resources. Determining the ecological implications of land-use decisions and policies is especially important for economies and communities that depend on the ecosystem services that originate from natural resources.

Review of comprehensive land plans revealed that basic environmental protection is recognized as an element of local and regional environmental sustainability, but ordinances are not yet as effective as they could be. Municipalities in this study recognized, through published ordinances, more ecosystem services than landscape functions, probably because ecosystem services relate directly to human needs. Ecosystem services and the ecological functions that support those services, however, were not well-protected through regulations. These municipalities could do more to protect ecosystem services and, equally as important, they could recognize the larger-scale land functions that support the production of all ecosystem goods and services.

Humans derive resources from natural environmental processes. Through landscape planning, municipalities can prevent or minimize flood damage, disease or pest outbreaks, polluted water and air, decaying ecosystems, degradation of livelihoods, and featureless landscapes. Policies developed for sustainable use of larger regional areas could protect and maintain natural functions and subsequent provisions of ecosystem services. Municipalities that incorporate landscape planning that benefits environmental and social health could justify their goals, purposes, and reasons for specific ordinances by backing them up with the wealth of knowledge about planning healthy landscapes and healthy communities.

The complex hydrogeologic character of karst makes land and watershed management in karst regions a challenge. Studies like this one can highlight gaps and needs in local and regional governments for better protection of natural and physical features, and resulting ecological services provided to human communities.

Landscape functions, ecosystem services, and any unique regional geography must be considered when people attempt to balance the conservation of natural resources with serving the public good. In support of local, regional, and global well-being of society and the environment, sustainable community development requires that we plan our land use within the context of the sustainable use of ecosystem services that humans can receive only from healthy landscapes.

REFERENCES

Alexander, E. C., Jr., Alexander, S. C., Piegat, J. J., Barr, K. and Nordberg, B. 2005. Dye Tracing Sewage Lagoon Discharge in a Sandstone Karst, Askov, Minnesota. *Proceedings of the Tenth Multidisciplinary Karst Conference.* ASCE Geotechnical Special Publication 144. Reston, VA: pp. 449-458.

Aspinall R. and Pearson, D. 2000. Integrated Geographical Assessment of Environmental Condition in Water Catchments: Linking Landscape Ecology, Environmental Modeling and GIS. *Journal of Environmental Management,* 59: 299-319.

Association of Minnesota Counties. 2002a. Land Use Management. For Your Information – A Publication of the Association of Minnesota Counties. St. Paul, MN.

Association of Minnesota Counties. 2002b. Transportation. For Your Information – A Publication of the Association of Minnesota Counties. St. Paul, MN.

Austin City Connection. 2010. *Watershed Protection - Development Review: Watershed Ordinances*. Austin, TX. [http://austintexas.gov/page/watershed-protection-ordinance-0]. Last accessed 01 November 2012.

Bacic, I. L. Z, Rossiter, D. G., and Bregt, A. K. 2006. Using Spatial Information to Improve Collective Understanding of Shared Environmental Problems at Watershed Level. *Landscape and Urban Planning,* 77: 54-66.

Bade, J. and Moss, P. 1999. Studies and Regulations in the Southwestern Illinois Karst. *Engineering Geology,* 52: 141-145.

Bateman, I. J., Harwood, A. R., Mace, G. M., Watson, R. T., Abson, D. J., Andrews, B., Binner, A., Crowe, A., Day, B. H., Dugdale, S., Fezzi, C., Foden, J., Hadley, D., Haines-Young, R., Hulme, M., Kontoleon, A., Lovett, A. A., Munday, P., Pascual, U., Paterson, J., Perino, G., Sen, A., Siriwardena, G., van Soest, D., and Termansen, M. 2013. Bringing Ecosystem Services Into Economic Decision-Making: Land Use in the United Kingdom. *Science,* 341: 45-50.

Beatley, T. 2000. Preserving Biodiversity - Challenges for Planners. *Journal of the American Planning Association,* 66: 5-20.

Beck, B. F. 1995. Karst Geohazards: Engineering and Environmental Problems in Karst Terrane. *Proceedings of the Fifth Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst.* Gatlinburg, TN.

Ben-Joseph, E. 2004. Future of Standards and Rules in Shaping Place: Beyond the Urban Genetic Code. *Journal of Urban Planning and Development,* 130: 67–74.

Bolund, P. and Hunhammar, S. 1999. Ecosystem Services in Urban Areas. *Ecological Economics,* 29: 293-301.

Bonacci, O., Pipan, T. and Culver, D. C. 2008. A Framework for Karst Ecohydrology. *Environmental Geology,* 56: 891-900.

Boyd, J. and Wainger, L. 2002. Landscape Indicators of Ecosystem Service Benefits. *American Journal of Agricultural Economics,* 5: 1371-1378.

Broward County. 2006. *Drainage and Natural Aquifer Groundwater Recharge Ordinance 2008-41.* [http://www.broward.org/PlanningAndRedevelopment/ComprehensivePlanning/Documents/drainageandnatural.pdf]. Last accessed 01 November 2012.

Brown, R. D. and Kockelman, W. J. 1996. Geologic Principles for Prudent Land Use: A Decisionmaker's Responsibility? *Environmental Geology and Water Sciences,* 8: 173-174.

Christiansen, K. and Bellinger, P. 1996*a*. Cave *Pseudosinella* and *Oncopodura* New to Science. *Journal of Cave and Karst Studies,* 58: 38-53.

Christiansen, K. and Bellinger, P. 1996*b*. Cave *Arrhopalites:* New to Science. *Journal of Cave and Karst Studies,* 58: 168-180.

Clark, T. W. 1992. Practicing Natural Resource Management with a Policy Orientation. *Environmental Management,* 16: 423-433.

Culver, D. C., Master, L. L., Christman, M. C. and Hobbs III, H. H. 2000. Obligate Cave Fauna of the 48 Contiguous United States. *Conservation Biology,* 14: 386-401.

Daily, G. C. 1997. *Nature's Services: Societal Dependence on Natural Ecosystems.* Washington, DC: Island Press.

Daily, G. C. 2000. Management Objectives for the Protection of Ecosystem Services. *Environmental Science and Policy,* 3: 333-339.

Daily, G. C., Polasky, S., Goldstein, J., Kareiva, P. M., Mooney, H. A., Pejchar, L., Ricketts, T. H., Salzman, J., and Shallenberger, R. 2009. Ecosystem Services in Decision Making: Time to Deliver. *Frontiers in Ecology and the Environment,* 21-28.

Dale, V. H., Brown, S., Haeuber, R. A., Hobbs, N. T., Huntly, N., Naiman, R. J., Riebsame, W. E., Turner, M. G. and Valone, T. J. 2000. Ecological Principles and Guidelines for Managing the Use of Land. *Ecological Applications,* 10: 639-670.

Davis, R. K., Hamilton, S. and Van Brahana, J. 2005. *Escherichia coli* in Mantled Karst Springs and Streams, Northwest Arkansas Ozarks, USA. *Journal of the American Water Resources Association,* 41: 1279-1287.

Diaz, S., Fargione, J., Chapin, F. S. and Tilman, D. 2006. Biodiversity Loss Threatens Human Well-Being. *PLoS Biology,* 4: 1300–1305.

Elliott, W. R. 2000. Conservation of the North American Cave and Karst Biota, in: H. Wilkens, D.C. Culver, and W.F. Humphreys, Eds. *Subterranean Ecosystems. Ecosystems of the World*, 30. Amsterdam: Elsevier: 665-689.

Fetterman, P., Kirkpatrick, P. G., Bell, H. and Lawhorne, D. 2003. Vegetative Communities and Morphological Characteristics of Selected Sinkholes in West-Central Florida, in: L. J. Florea, H. L. Vacher, and E. A. Oches, Eds. *Karst Studies in West Central Florida: USF Seminar in Karst Environments*. Southwest Florida Water Management District. Tampa, FL: pp. 65-77.

Fiedler, A. K., Landis, D. A. and Wratten, S. D. 2008. Maximizing Ecosystem Services from Conservation Biological Control: The Role of Habitat Management. *Biological Control,* 45: 254-271.

Furley, P. A. and Newey, W. W. 1979. Variations in Plant Communities with Topography over Tropical Limestone Soils. *Journal of Biogeography,* 6: 1-15.

Gao, Y., Alexander, E. C. and Tipping, R. G. 2002. The Development of a Karst Feature Database for Southeastern Minnesota. *Journal of Cave and Karst Studies,* 64: 51–57.

Gober, P., Brazel, A., Quay, R., Myint, S., Grossman-Clarke, S., Miller, A., and Rossi, S. 2010. Using Watered Landscapes to Manipulate Urban Heat Island Effects. *Journal of the American Planning Association,* 76: 109-121.

Grant, J., Manuel, P. and Joudrey, D. 1996. A Framework for Planning Sustainable Residential Landscapes. *Journal of the American Planning Association,* 62: 331–345.

Guo, Z., Xiao, X. and Li, D. 2000. An Assessment of Ecosystem Services: Water Flow Regulation and Hydroelectric Power Production. *Ecological Applications,* 10: 925-936.

Handbook for Minnesota Cities. 2007. Part II. Elections, Elected Officials, and Council Meetings. Chapter 7: Meetings, Motions, Resolutions, and Ordinances. League of Minnesota Cities. St. Paul, MN.

Halihan, T., Wicks, C. M. and Engeln, J. F. 1998. Physical Response of a Karst Drainage Basin to Flood Pulses: Example of the Devil's Icebox Cave System Missouri, USA. *Journal of Hydrology,* 204: 24-36.

Hart, A. J. 2008. The Economic Impact of Recreational Trout Angling in the Driftless Area, NorthStar Economics, Inc. Madison, WI.

Huppert, G. N. 1995. Legal Protection for Caves in the United States. *Environment Geology,* 26: 121-123.

Jenerette, G. D., Harlan, S. L., Stefanov, W. L., and Martin, C. A. 2011. Ecosystem Services and Urban Heat Riskscape Moderation: Water, Green Spaces, and Social Inequality in Phoenix, USA. *Ecological Applications*, 21: 2637-2651.

Kemmerly, P. R. 1993. Sinkhole Hazards and Risk Assessment in a Planning Context. *Journal of the American Planning Association,* 59: 221-230.

Kobza, R. M., Trexler, J. C., Loftus, W. F. and S. A. Perry. 2004. Community Structure of Fishes Inhabiting Aquatic Refuges in a Threatened Karst Wetland and its Implications for Ecosystem Management. *Biological Conservation,* 116: 153-165.

LaMoreaux, P. E., Powell, W. J. and LeGrand, H. E. 1997. Environmental and Legal Aspects of Karst Areas. *Environmental Geology,* 29: 23-36.

Lankao, P. R. 2007. How Do Local Governments in Mexico City Manage Global Warming? *Local Environment,* 12: 519-535.

Lathrop, R. G. and Bognar, J. A. 1998. Applying GIS and Landscape Ecological Principles to Evaluate Land Conservation Alternatives. *Landscape and Urban Planning,* 41: 27-41.

Lewis, J. J., Moss, P., Tecic, D. and Nelson, M. E. 2003. A Conservation Focused Inventory of Subterranean Invertebrates of the Southwestern Illinois Karst. *Journal of Cave and Karst Studies,* 65: 9-21.

Mahler, B. J. and Lynch, F. L. 1999. Muddy Waters: Temporal Variation in Sediment Discharging from a Karst Spring. *Journal of Hydrology,* 214: 165-178.

Manda, A. K. and Gross, M. R. 2006. Identifying and Characterizing Solution Conduits in Karst Aquifers through Geospatial GIS. Analysis of Porosity from Borehole Imagery: An Example from the Biscayne Aquifer, South Florida USA. *Advances in Water Resources,* 29: 383-396.

McCormick, T. J. 2007. The Driftless Area. *Minnesota Conservation Volunteer,* 70: 8-17.

Milder, J. C., Lassoie, J. P. and Bedford, B. L. 2008. Conserving Biodiversity and Ecosystem Function Through Limited Development: An Empirical Evaluation. *Conservation Biology,* 22: 70-79.

Millennium Ecosystem Assessment [MA]. 2005. Ecosystems and Human Well-Being: Our Human Planet. Island Press, Washington, D.C.

Miller, J. R., Groom, M., Hess, G. R., Steelman, T., Stokes, D. L., Thompson, J., Bowman, T., Fricke, L., King, B. and Marquardt, R. 2008. Biodiversity Conservation in Local Planning. *Conservation Biology,* 23: 53-63.

Municipal Code Online Library. 2008. Code of Ordinances, City of Tampa, Florida.

Chapter 17.5, Article V. Upland Habitat Protection. Tampa, FL.

Neill, H., Gutierrez, M. and Aley, T. 2004. Influences of Agricultural Practices on Water Quality of Tumbling Creek Cave Stream in Taney County, Missouri. *Environmental Geology,* 45: 550-559.

Niemela, J., Saarela, S., Soderman, T., Kopperoinen, L., Yli-Pelkonen, V., Vare, S., and Kotze, D. J. 2010. Using the Ecosystem Services Approach for Better Planning and Conservation of Urban Green Spaces: A Finland Case Study. *Biodiversity Conservation,* 19: 3225-3243.

Pastor, J. 2005. Thoughts on the Generation and Importance of Spatial Heterogeneity in Ecosystems and Landscapes. G. M. Lovett, C. G. Jones, M. G. Turner, K. C. Weathers, eds. *Ecosystem Function in Heterogeneous Landscapes*. New York, NY: pp. 49-66.

Peck, S. B. and Christiansen, K. 1990. Evolution and Zoogeography of the Invertebrate Cave Faunas of the Driftless Area of the Upper Mississippi River Valley of Iowa, Minnesota, Wisconsin, and Illinois, U.S.A. *Canadian Journal of Zoology,* 68: 3-88.

Peterson, T. A. 2005. Sensitivity to Pollution of the Uppermost Aquifers, Geologic Atlas of Wabasha County, Minnesota, County Atlas Series C-14, Part B, Plate 10, Minnesota Department of Natural Resources, St. Paul, MN.

Quay, R. 2010. Anticipatory Governance – A Tool for Climate Change Adaptation. *Journal of the American Planning Association,* 76: 496-511.

Quinlan, J. F. 1986. Legal Aspects of Sinkhole Development and Flooding in Karst Terranes: 1. Review and Synthesis. *Environmental Geology and Water Sciences,* 8: 41-61.

Ralston, M. R. and Oweis, I. S. 1999. Geotechnical Engineering Considerations for Stormwater Management in Karst Terrain. Southeast Pennsylvania Stormwater Management Symposium, Villanova University, Villanova, PA.

Ruhl, J. B., Kraft, S. E., and Lant, C. L. 2007. *The Law and Policy of Ecosystem Services.* Washington, DC: Island Press.

Selman, P. 2002. Multi-Function Landscape Plans: A Missing Link in Sustainability Planning. *Local Environment,* 7: 283-294.

Shelton, D., Cork, S., Binning, C., Parry, R., Hairsine, P., Vertessy, R. and Stauffacher, M. 2001. Application of an Ecosystem Services Inventory Approach to the Goulburn Broken Catchment, In: I. Rutherford, F. Sheldon, G. Brierley, and C. Kenyon, Eds. *Third Australian Stream Management Conference.* Cooperative Research Centre for Catchment Hydrology: Brisbane, Australia: pp. 157-162.

Stoorvogel, J. J. and Antle, J. M. 2001. Regional Land Use Analysis: The Development of Operational Tools. *Agricultural Systems,* 70: 623-640.

Theobald, D. M., Spies, T., Kline, J., Maxwell, B., Hobbs, N. T. and Dale, V. H. 2005. Ecological Support for Rural Land-Use Planning. *Ecological Applications,* 15: 1906-1914.

Thorn, W. C., Anderson, C. S., Lorenzen, W. E., Hendrickson, D. L. and Wagner, J. W. 1997. A Review of Trout Management in Southeast Minnesota Streams. *North American Journal of Fisheries Management,* 17: 860-872.

Tipping, R. 2002. Karst Features of Wabasha County, Minnesota. Runkel, A.C., Project Manager, Contributions to the Geology of Wabasha County, Minnesota: Minnesota Geological Survey Report of Investigations 59. St. Paul, MN.

Tratalos, J., Fuller, R. A., Warren, P. H., Davies, R. G. and Gaston, K. J. 2007. Urban Form, Biodiversity Potential and Ecosystem Services. *Landscape and Urban Planning*, 83: 308-317.

Tscharntke, T., Klein, A. M., Kruess, A., Steffan-Dewenter, I. and Thies, C. 2005. Landscape Perspectives on Agricultural Intensification and Biodiversity - Ecosystem Service Management. *Ecology Letters,* 8: 857-874.

U.S. Census Bureau. 2000. *United States Census 2000.* [http://www.census.gov/

main/www/cen2000.html]. Last accessed 01 November 2012.

United States Geological Survey [USGS]. 2010. *Karst and the USGS.* [http://water.usgs.gov/ogw/karst/index]. Last accessed 01 November 2012.

Veni, G. 1999. A Geomorphological Strategy for Conducting Environmental Impact Assessments in Karst Areas. *Geomorphology,* 31: 151-180.

Viglizzo, E. F., Paruelo, J. M., Laterra, P., and Jobbagy, E. G. 2011. Ecosystem Service Evaluation to Support Land-Use policy. *Agriculture, Ecosystems and Environment,* 154: 78-84.

Washington State. 2010. *Department of Ecology: Critical Aquifer Recharge Areas. Washington, USA.* [http://www.ecy.wa.gov/programs/wq/grndwtr/cara/index.html]. Last accessed 01 November 2012.

Western Governor's Association [WGA]. 2011. [http://www.westgov.org] (last accessed 01 November 2012).

White, E. L., Aron, G. and White, W. B. 1986. The Influence of Urbanization on Sinkhole Development in Central Pennsylvania. *Environmental Geology and Water Sciences,* 8: 91-97.

White, W. B. 1988. Geomorphology and Hydrology of Karst Terrains. Oxford UK: Oxford University Press.

Wicks, C., Kelley, C. and Peterson, E. 2004. Estrogen in a Karstic Aquifer. *Ground Water,* 42: 384-389.

Woolf, T. and Sommer, A. 2004. Local Policy Measures to Improve Air Quality: A Case Study of Queens County, New York. *Local Environment,* 9: 89-95.

Zhou, W. 2007. Drainage and Flooding in Karst Terranes. *Environmental Geology,* 51: 963-973.

Ziegler, S. S. and Williams, M. A. 2008. Land-Use Policy to Conserve Resources in Southeastern Minnesota. *CURA Reporter,* 38: 13-21.