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KARST ENVIRONMENTS: PROBLEMS, MANAGEMENT, HUMAN IMPACTS, AND SUSTAINABILITY AN INTRODUCTION TO THE SPECIAL ISSUE

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Karst systems are extremely complex, and due to a number of geological and hydrological characteristics, they can be included among the most fragile and vulnerable environments in the world. Complexity of karst is expressed by the enormous variations existing in different karst regions (White, 1988). The difficulties inherent in such variability were appropriately described by Beck (1999), who wrote, ''Learning to understand the systematics of karst terrain and how to deal with it safely requires serious effort—often a lifetime of study.'' This means, in other words, that man must make a strong effort to learn to live ''in harmony with'' karst, rather than to live ''on'' karst. Many problems we face when interacting with karst environments are best solved through changes in human systems rather than through alterations of karst environments. This is because subtle changes in fragile karst systems change them significantly.

Because karst covers 10 to 20% of the earth's surface and provides 40 to 50% of the world's drinking water (Ford and Williams, 2007), it requires a specific approach to mitigate negative human impacts and allow sustainable development. In this sense, protection of karst groundwater is essential in many countries. Karst hydrologic systems are highly vulnerable to pollution, water withdrawals, and changes in land use (Bakalowicz, 2005; Calò & Parise, 2009). In addition, the dissolution of limestone creates voids in the subsurface that can lead to collapses that directly affect the built environment by inducing severe damage, property loss, and disruptions to daily life. Management of karst environments is a very delicate matter, and how to manage pollution, karst hazards, and human impacts on karst landscapes is a question worthy of discussion (White, 1990; Parise and Pascali, 2003).

Many populated areas of the world obtain drinking water from karst aquifers, and numerous urban areas are underlain by karstified bedrock. Consequently, karst systems pose a number of engineering and environmental problems (Calembert, 1975; Legrand, 1984; Ford, 1993; Williams, 1993; Johnson and Neal, 2003) that are continuously increasing as development extends over these areas. Building on cavernous bedrock and sinkhole-prone areas is a challenging issue for geoscientists and engineers (Waltham et al., 2005; Del Prete et al., 2010); appropriate management of karst areas has to carefully take into account the possibility of the presence of underground voids of both natural and anthropogenic origin in order to mitigate the risk related to sinkholes.

Problems in karst, karst management, and the sustainability of karst environments are receiving growing interest around the world due to the importance of natural resources and the need to protect and properly exploit them. In many karst regions, the human impact on these fragile ecosystems is significant (van Beynen and Townsend, 2005; Calò and Parise, 2006; van Beynen et al., 2007; North et al., 2009). This is especially true along coasts where seasonal increases in population have deleterious impacts. There is, therefore, the need for more work dedicated to understanding human-altered karst landscapes via assessing alterations of natural systems and the repair of karst ecosystems, measuring karst disturbance and sustainability, managing karst lands in urbanized and urbanizing areas, and assessing changes in karst hydrology.

Engineering problems in karst have been the main topic of several conferences and meetings in the last decades that resulted in interesting volumes and special issues. From 1984 to 2011, twelve Multidisciplinary Conferences on Sinkholes and the Engineering and Environmental Impacts of Karst have been organized in the United States (Beck, 1999, 2002). In Europe, since 2004, problems related to karst environments have been the subject of specific sessions at the General Assembly of the European Geosciences Union within the framework of the Natural Hazards Program. In many cases, the most significant outcomes from these sessions have been published as special issues of peer-reviewed journals (Parise and Gunn, 2005; Parise et al., 2008, 2009; De Waele et al., 2011) or as a book (Parise and Gunn, 2007). Notwithstanding these efforts, little attention is given to these issues in karst landscapes, and few regions of the world fully understand or appropriately manage karst areas.

In an attempt to draw the attention of the scientific world on the need to specifically address issues in karst settings, we organized a poster session titled Karst Environments: Problems, Management, Human Impacts, and Sustainability at the Annual Meeting of the Geological Society of America in Denver, Colorado, on November 2, 2010. The session hosted two invited presentations and twenty-three other submissions on a variety of topics and was sponsored by the Karst Waters Institute, the National Cave and Karst Research Institute, and the GSA Hydrogeology and Quaternary Geology and Geomorphology Divisions.

In this special issue, a selection of the papers from that session is presented. The papers explore current research on how humans are interacting with karst, with a distinct focus on management and sustainability. This issue contains eight articles on a number of topics. Mick Day and Bill Reynolds summarize work that they have done at

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Five Blue Lakes National Park in Belize. The changing hydrology of the Belizean karst system greatly impacts the nature of tourism in the region. Along similar investigative lines, Francesco Fiorillo and Gerardo Ventafridda provide evidence from five springs in southern Italy that suggest that the aquifer systems in that region are more complex than originally thought. The authors provide detailed reasoning for understanding how aquifer catchments drain during the dry season. Benjamin Tobin and Benjamin Schwartz detail a fascinating study of marble karst aquifers in Sequoia and Kings Canyon National Parks in the United States. Their work is among a few that provide detailed quantitative data on spring discharge in alpine karst systems. Phil van Beynen and his co-authors discuss a new approach to describing karst using a sustainability index. As karst lands become more threatened, the authors provide a unique way to measure current management conditions.

Vincenzo Festa and his co-authors discuss sinkhole hazards in the Salento Peninsula of Italy, with a case study from Lecce. They provide a historic description of sinkhole formation there to better understand future sinkhole evolution in the region. Maria Asuncion Soriano and her colleagues focused their attention on sinkhole evolution in the Ebro Basin of Spain. Their work examined the geologic history of paleosinkholes and their role in the water supply in the region. Marco Taviani and his colleagues also looked at paleokarst landscapes. Their work took them to the south Adriatic shelf on the Apulian coast of Italy. They offer a better understanding of the complex issues associated with karst-landscape development in the Mediterranean basin. Cipriano di Maggio and his co-authors round out the contributions from Europe by providing a detailed description of the karst of Sicily and how it is managed. They offer several interesting observations about environmental policy and management in the region.

We hope that the readers of the *Journal of Cave and Karst Studies* enjoy these articles and that they advance the understanding of karst and karst management in some way.

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