ENVIRONMENTAL IMPACTS ASSESSMENTS

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Karst areas are diversely rich in resources, yet are the world's most vulnerable landscapes to environmental impacts. The Earth's most productive springs and water wells occur in karst. The space provided by caves often provides habitats for rare and unusual species, serving as models of evolution and ecosystem development. Other species, such as bats, are internationally important as pollinators, seed dispersers, and controllers of crop and other insect pests. Hydrologically inactive caves offer stable environments that preserve many of the greatest archaeological and paleontological sites from the elements that would destroy them on the surface. Caves and surface karst terrains provide a wealth of recreational and scenic attractions. Paleokarst areas often contain tremendous deposits of oil, lead, zinc, and other fuels and minerals. The karstic bedrock itself, usually limestone, is often quarried for use in construction.

Historically, karst areas have not been heavily populated or utilized, and thus not heavily impacted. People have lived along the margins of karst, enjoying the benefits of springs, but most karst resources were difficult to access or of little direct or recognized economic benefit. However, technological advances in the 20th century changed this situation. Water and mineral resources are now easily extracted from karst, and many urban areas have grown onto karst areas. The underground spaces that offer protection and habitats also allow the consequences of surface activities, such as contaminants, to easily enter the subsurface and degrade those resources.

Environmental impacts assessments (EIA) are increasingly used to limit the adverse impacts of human activities on resources important to the health of human and non-human ecosystems. The unique attributes of karst areas require assessment methods specifically designed for those terrains. DRASTIC (Aller et al, 1987), pump tests, monitoring wells, and other techniques that are effective in assessing and managing non-karst terrains, are often poorly effective to ineffective in karst. While several scientific disciplines need to be considered in assessing karst, a hydrogeologic EIA should first be conducted, since it defines the physical parameters of a study area and provides a conceptual model of karst development as a foundation for the other fields of research.

Three primary hydrogeologic EIA models for karst have been published and used. One or more can be used within a given investigation, based on the purpose, scale, and detail of study. Doerfliger, Jeannin & Zwahlen (1999) proposed EPIK to assess the vulnerability of karst terrains through the use of air photo interpretation, tracer tests, geophysical data, and geomorphological mapping in karst spring drainage basins. The EPIK system uses the resulting data to define an area's Epikarst (surface karst features), Protective cover (soil), Infiltration conditions, and Karst drainage (degree of solutional conduit development). The characteristics of an assessed karst watershed area are matched to a category under each EPIK factor. The categories have numerical values which are multiplied by a constant for the EPIK factor, and the results are summed to identify the area's degree of sensitivity with respect primarily to groundwater contamination. This vulnerability mapping method has broad application for both local and regional level EIA.

A second karst hydrogeologic EIA model was proposed by the American Society for Testing and Materials (ASTM, 1995) and extended by the US Environmental Protection Agency (Schindel et al., 1997). A conceptual model of the karst aquifer under study is first developed based on existing information and modified as new information is collected. Initially, well and spring data are usually most available and used to examine water-table elevations, differences in permeability and chemistry, and responses to recharge. Karst-specific data are then considered, surveying the location, type, and geologic setting (fractures, strata, etc.) of caves and other karst features. The next step, in many investigations, is to design a series of tracer tests to determine groundwater drainage basins, flowpaths, travel times, storage, dilution, and dispersion. These factors change with ground-water discharge and should be conducted, if possible, during base flow and storm flow conditions. Geophysical techniques, such as electrical resistivity and microgravity, can be used where it is necessary to locate voids that are not accessible through known caves. This is usually done for relatively small areas since these techniques are labour, time, and cost intensive.

Veni (1999) proposed a third karst hydrogeologic EIA strategy for areas where tracer testing and geophysical techniques are not possible or available. This method examines geomorphological and hydrological characteristics of karst areas and features to assess their relative permeability and their potential vulnerability. The potential for doline (sinkhole) collapse is often best identified through such methods. This strategy can be applied regionally as well as to specific features, and is adjusted according to the dominant characteristics of karst within each study area. It can also be applied to develop superior conceptual models of the karst and / or better interpret the results of the tracer and other studies. Additionally, this strategy requires defining what level of impacts on karst resources is sustainable in order to truly determine the consequences.

All hydrogeologic karst EIA methods suffer from the failing that they identify areas and features of relatively greater or lesser vulnerability, and land managers not familiar with karst often interpret less vulnerable areas as not vulnerable. Scientists conducting EIA in karst should stress to land managers that by the nature of karst landscapes, all areas are vulnerable, only highly vulnerable areas are distinguished, and that karst cannot be adequately managed solely on a feature-by-feature basis. Studies on the relationship of water quality to non-natural impervious land cover (roads, parking lots, buildings etc.) show adverse environmental impacts significantly increase when impervious cover exceeds 15% of a surface watershed. Veni (1999) recommended a maximum of 15% impervious cover as an effective means of protecting karst aquifers when coupled with protection of critical areas identified by field surveys.

Rare, endangered, or otherwise important species occur in many karst areas. They include aquatic species such as invertebrates, fish and salamanders, and terrestrial species, such as bats and invertebrates. While these species may be protected by the above hydrogeologic EIA methods, specific biological EIA methods are needed where hydrologic protection measures are not present or are inadequate for karst fauna. For example, water quality protection measures may not protect bats as much as not disturbing them during their hibernation. The above geo-morphological EIA strategy is applicable to biology, by delimiting areas where important faunas should occur and which species may be present.

Following a review of biological data, the first step of a biological EIA is a presence-absence survey for the fauna of concern in the study area. Some rare species will require multiple surveys to adequately determine if they are likely to be present. Others, such as migratory bats, can only be surveyed at certain times of year. A standard for the number and method of surveys may need to be established appropriate to the fauna. US Fish and Wildlife Service (2000) provides an example of karst biological survey standards. Monitoring of the fauna is also a key component of a karst biological EIA, to distinguish natural changes within the ecosystem from induced impacts and to determine what impacts are sustainable. While monitoring is usually not within the scope of a specific assessment, experience from monitoring studies with the species of concern should be incorporated into the karst biological EIA.

A significant portion of karst ecosystems may not be accessible or directly observable through caves and is thus difficult to assess in a karst biological EIA. This problem is especially important where quarries may largely or completely destroy the habitat and fauna, or where the habitat and fauna may be significantly altered and impacted by extensive urban and industrial development. A regional analysis of species localities relative to geologic factors may delineate the species' probable distribution and the degree of impacts they can withstand. Recovery plans for endangered karst invertebrate species have been based on such analyses (e.g. O'Donnell, Elliott & Stanford, 1994).

Karst EIA for cultural and paleontological materials also requires presence-absence surveys. Regional analysis can be helpful to identify areas where such materials are likely to occur but is less reliable than with similar biological studies. Materials present on the land surface may or may not be good indicators of materials in caves. Some past cultures and animals avoided caves while others were drawn to them. In either case, significant deposits may be present in caves due to deliberate or accidental accumulations. Both above and below ground, relatively recent sediments, free of cultural or paleontological materials, may bury or obscure older important deposits.

Cultural and paleontological karst EIA techniques commonly begin with detailed grid searches of the land surface. Such searches are also effective in hydrogeologic EIA in locating karst and other geologic features. Shovel tests are often necessary to evaluate potential deposits. Areas in caves that are likely to accumulate sediments, especially near entrances, should also be shovel tested, although such tests may be insufficient to characterize deep deposits. In some cases, geophysical methods can be used to evaluate a deposit's potential for significant materials and guide excavation or preservation strategies. In areas that may be lost to quarrying or other activities, evaluation methods may need to be modified into salvage operations if detailed studies are not feasible.

The complexity of karst terrains, their multiple and often difficult to define resources, and their high vulnerability to adverse impacts, requires prudence in EIA recommendations. There remains a lot to learn about how to best evaluate some attributes of karst and how to effectively protect and manage them. EIA recommendations should therefore be coupled with strategies recommended for the identification, delineation, and establishment of preserved or protected areas, appropriate management and maintenance of those areas, gating of caves and areas as necessary, and monitoring of resources within those areas, to determine the effectiveness of the recommended actions and the EIA process.

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See also Conservation: Cave Biota; Conservation: Protected Areas; Groundwater Protection; Monitoring

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