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Managing environmental problems in Cuban karstic aquifers

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The Cuban archipelago is formed by about 4000 small islands (named “cayos”) that surround the two main islands: Cuba, and the Isle of Youth (Isla de la Juventud). Cuban karst covers almost 66% of the overall territory. The most important aquifers are of karstic nature and comprise 80% of the countrys groundwater resources. These aquifers are mainly unconfined and built by Miocene carbonate rocks morphologically expressed as very gentle coastal flatlands. Only a small part of the total karst (about 7500 km2) is occupied by low to medium height mountains of Jurassic to Paleogene rocks. While in the flatland conduit and diffuse flows are observed, with the latter dominating, in the mountains conduit flows represent the main process. Due to the narrow and elongated (W-E to NW-SE) configuration of Cuba, the main water divide determines the presence in the island of small catchment basins directed to the north and the south. The largest catchments, on the other hand, are found in the few rivers running eastward or westward. Because of these features, that combine with the extreme rainfall events typical of the humid tropics, flashfloods may often characterize the response to tropical heavy rains. Economy in Cuba was traditionally based on agriculture, as in most of the Caribbean. In the last decades, however, other activities are rising in importance, including mining, light industry, and tourism. A phenomenon of high concentration of the population in the capital of the country (La Habana) and in the main cities has developed since the 1960’s and only stopped and slightly reverted locally in the last five years. Thus, the geological, geographical and economic framework of the country defines the environmental problems that should be managed for an adequate protection of groundwater quality. This paper offers an overview of the main pollution sources of groundwater in Cuba and discusses the assessment of the vulnerability to aquifers in the particular case of a karstic territory in the humid tropics. Vulnerability

of aquifers depends on several factors linked with the geological structure, climatic conditions, land and water use and economic framework. Karst aquifers, in particular, are extremely complex, and assessment of the related vulnerability is difficult because of the heterogeneity and anisotropy of the water bearing strata, the close relationship between landforms and drainage, and the degree of hydrological activity of the karstic system. Karst systems are characterized by the following properties: a) thermodynamically, karst is an open system interacting with the surrounding media; b) the variables describing the physical properties of the system show a progressive three-dimensional anisotropy; c) for any kind of basic measure of a characteristic length (area, volume, length, effective diameter) the karstic space is rigorously hierarchisized; d) four types of constitutive spaces are then developed, generically designed (in decreasing order of characteristic length) as caves, joints, pores and solid matrix; e) each of the constitutive spaces exhibits their own flow domain and, among them, an active exchange of mass, moment and energy takes place; f) responses to external or internal (natural or artificial) inputs of mass, energy and moment are hierarchically modulated by the system's internal structure and capability to assimilate stresses; g) the scale factor exerts a strong influence on the physical meaning and stochastic behavior of the physical properties; h) the system, and its physical properties, are highly time dependent at different space and time scales; i) the karstification process is irreversible; its evolution is unidirectional towards increasing levels of entropy.

The properties above mean that anisotropy and heterogeneity are due to the differentiated development of karstification in carbonate rocks. Morphological features are developed selectively. Therefore they behave also differently with respect to vertical or horizontal flows. Dolines and vertical shafts or horizontal and subhorizontal caves absorbing overland or streamflow are the carriers of great volumes of water entering rapidly the aquifer system. Responses to these concentrated inputs are more or less rapid, depending on the initial state of the system and its inertial properties. Commonly, when connected to water table aquifers, the response tends to be fast, with a piston-flow behavior that is a very useful pattern to explain and mathematically describe the hydrodynamics of the aquifer. Less developed karst features, clay-filled vertical caves, joints and fissures, behave more slowly to inputs, delaying flow to the saturated zone and, in turn, producing a second peak in groundwater levels or at least a delayed response to mass transfer. These two extreme behaviors produce a complex interaction and behavior of the system with respect to mass transport processes. While physical properties are different for each of the involved spaces, time responses are also different. The so-called multiphase flow is most commonly observed in karstic systems than anywhere. An intensive karst development in this unsaturated zone allows two main infiltrating paths to groundwaters: i) a fast concentrated recharge takes place along vertical shafts or in horizontal or subhorizontal caves; surface flow to these features occurs through a diffuse overland flow, or a concentrated - channeled flow (streams entering caves); ii) a slow, diffuse recharge takes place along less karstified pores, joints and fissures. Both mechanisms are also important to explain pollution hydrodynamics in karstic terrains. Different concentrations, flow paths and arrival times are controlled by the recharge system. While a group of boundary conditions concerning infiltration capability depends on the differentiated karst development, the other group is influenced by the anthropogenic activities in karst. Therefore, karst land and water use may strongly change the vulnerability of the system. This paper eventually discusses, through selected examples from different regions of the country, the extension and management of the major pollution sources to groundwater identified in Cuba, including sea water intrusion, agricultural practices, waste deposits, industrial activity, mining, oil and gas development.