Chapter 16
Water Resources Management in Small Mountain Watersheds in the Humid Tropics: The Hydrologic System of the Santo Tomas Cave System, Pinar del Rio, Cuba

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Abstract The Santo Tomas cave system is located in an area of tower karst, with rolling hills and valley streams. The Santo Tomas caves, near Pinar del Rio, Cuba, consist of about 47 km of underground conduits, which have periodic contact with the five separate surface streams of the area. Four central principles of environmental management: legal control and regulation, administrative permits and licenses, economic impacts, and research and public education, are reviewed with regard to the Santo Tomas caves.

Keywords Water resources management • Mountain watersheds • Humid tropics • Cuba

16.1 Introduction

According to Rodríguez-Becerra and Espinoza (2002), the instruments of environmental management can be grouped into four categories:

1. The instruments of direct regulation, also known as command and control based on the laws, procedures, standards and regulations and on the equation coercion-punishment; in other words this is the usual way the law is accomplished but applied to the environmental behaviors of society.
2. The administrative instruments that consist of environmental licenses, permits and the other ways to acquire the rights to use the environment according to a particular legislation. The environmental license has been the most common instrument within this category.
3. The economic instruments are oriented to promote that the market forces dominate the accomplishment of the environmental goals of the society.

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4. Education, research, technical assistance and the environmental information integrates the last category.

No control can be exerted on something that is not known. Therefore, for adequate hydrological and environmental management of a particular karst environment and its specific properties should be taken into account. In the particular case of the karst mountains of the Humid Tropics hurricane prone area the sustainable management should be based on the following instruments of knowledge:

- The laws governing the organization of the surface runoff.
- The local development of the hydrological karst system
- The physical and biogeochemical hydrodynamics.
- The local level of social and economic development
- The social and natural vulnerability and hydrologic risks.

This paper stresses the importance of the instruments of knowledge in the environmental management of the karst mountains in the Humid Tropics in the examples of the hydrologic system of the Santo Tomas Cave System.

16.2 Main Hydro-Environmental Features of the Karst Mountains in the Humid Tropics

The mountain karst of the Humid Tropics shows several particular features:

- Its location in a hurricane prone area with characteristics of heavy short duration rains.
- A surface drainage developed in very small catchments where flash floods are the distinctive expression of fluvial response to rainfall.
- A low storage capacity of the fluvial basin, where granular aquifers linked to the fluvial basins are commonly very low productive or negligible.
- The development of underground watercourses commonly in superimposed cave levels with a variable degree of integration but where important modifications of runoff take place. Therefore, absorbent and emissive (discharge) slopes are commonly recognized.
- Flood hydrographs show differences due to modifications associated with hydraulic restrictions in the cave system (such as gallery enlargements, lakes, embankments, cascades, sinuosity, meandering and other morphological features). Therefore, usually the input one-peak flood hydrograph is transformed into a two or three peak flood hydrograph at the outlet (emissive slope).
- Depending on the local organization of the fluvial subterranean course and on the connection among the conduits the self-depuration capability of the karst system is very variable. While in some cases a good re-aeration improves the concentration of Dissolved Oxygen even in depleted streams; in other cases no modifications occur that jeopardize the water quality downstream.
- In this case, downstream communities use to show a high vulnerability to contamination.

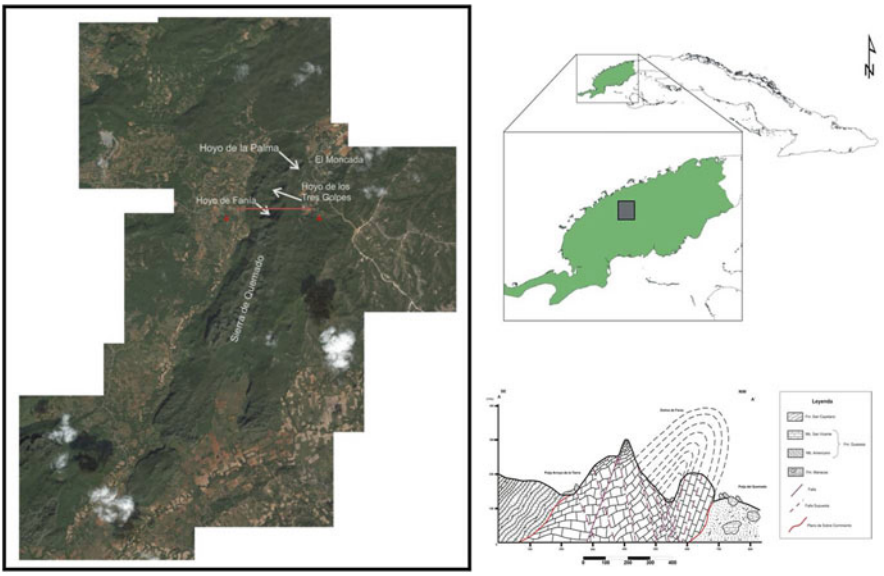

Fig. 16.1 Location map of the study area

- Almost all of these karst watersheds are rural communities with a low-income economy. When population is concentrated upstream the absorbent slope of the mountain high nutrient loads are usually concentrated and delivered after scarce or no treatment to the streams entering the karst massif.
- In the particular case of the tower karsts of the studied area (as it is in other towers, turm and cockpit karsts of the Humid Tropics), no population lives in the summits of the hills but in the surrounding non-karst or fluviokarstic valleys (or even in the poljes). Therefore, the main paths of contamination are the horizontal and sub-horizontal water courses (concentrated or even diffuse) that enter the cave systems and not the vertical recharge from the top of the hills.

16.3 The Santo Tomas Cave System Hydrologic System

The Sierra de Quemado (Figs. 16.1 and 16.2), one of the most important karstic mountain ranges of Cuba is located almost 200 km West of La Habana, Cuba's capital. Showing a typical tower (kegel) karst morphology of step sided walls and rounded submits highly karstified, the system is built of carbonate rocks of Upper Jurassic – Lower Cretaceous surrounded by Lower Jurassic sandstones, schists and shales. Younger Paleogene sediments are also present in the area where a typical Alpine tectonics with important overthrusting dominates (Furrazola-Bermudez et al. 1978; Psczolkowski 1987; Piotrowska 1987). The surrounding valleys are developed at an average altitude of 100 m a.s.l., and the summit of the sierra does not exceed 300 m above ground level.

Fig. 16.2 Southeast partial view of the absorbent slope of the Sierra de Quemado

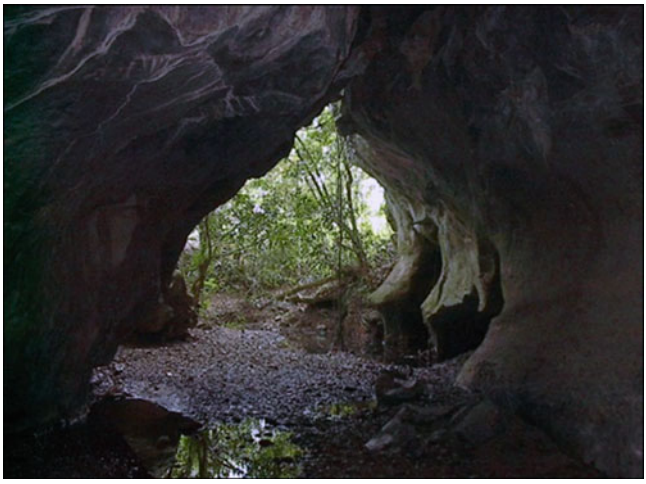

Fig. 16.3 Sumidero (ponor) of the Santo Tomás river during the dry season

Five small streams (Santo Tomás, Bolo, Peñate, Los Cerritos y Arroyo de la Tierra) run from the non-karstic Lower Jurassic sediments in very short courses and enter one each on the Eastern slope of the Sierra de Quemado through five ponors. The best known of them are the Santo Tomás (Fig. 16.3) and Peñate (Fig. 16.4). After emerging at the other slope, all the five streams join into the La Caoba stream, a tributary of the Cuyaguateje River, the largest watershed in Western Cuba. Upstream there is a concentrated population of almost 1,000 inhabitants (El Moncada community). Downstream at the discharge slope in the Isabel Maria Valley, dispersed farmers use the

Fig. 16.4 Sumidero (ponor) of Arroyo Peñate

emerging waters to satisfy their demand. El Moncada has the only municipal water supply system in the territory.

16.4 Scope of the Hydrologic Management of a Karst Mountain System

Only the most important features of the scope will be mentioned here.

16.4.1 The Organization of the Surface Runoff

Surface runoff is governed by very low concentration times due to high slope small watersheds of very small order. The most important features concerning this item are the transformation of the flood hydrograph in response to the same storm event because of the hydraulic restrictions associated with the cave development, the small aquifer storage capacity of the fluvial basin. Another important feature is associated with the heavy rainfall gradient that leads the formation of discharge floods associated with rains circumscribed only to the top of the hills and not to the valleys.

16.4.2 The Local Development of the Hydrologic Karst System

The degree of organization and integration of the subterranean conduits is of prior importance. Superimposed cave levels and interconnected meandering galleries allow flowing retardation with major modifications of the input hydrograph than almost rectilinear galleries. The small differences in altitude also allow that lateral flow can

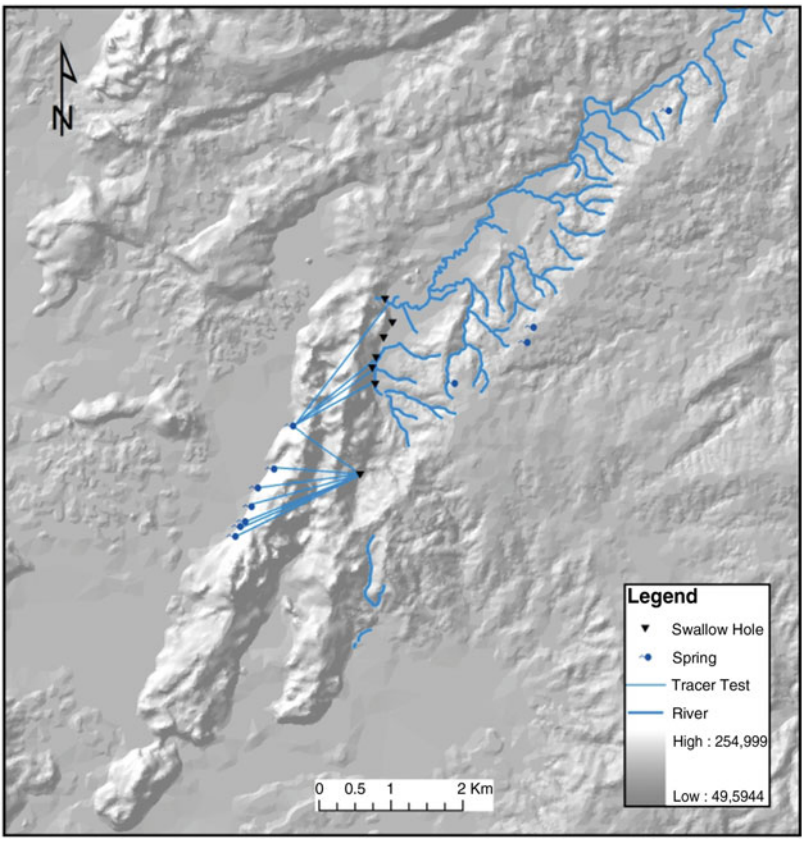

Fig. 16.5 Hydraulic connections defined by tracer tests

connect the entering streams; and huge lakes could last several days upstream, changing the flow patterns and the nutrient loads to the system. The Santo Tomás Cave System is a well-integrated 47 km of connected underground galleries; however, tracer tests (Molerio et al. 2004a) have shown that this figure could be duplicated. Figure 16.5 shows the interconnections discovered by means of tracer tests and shows the hydraulic relations among the components of the cave system.

16.4.3 The Physical and Biogeochemical Hydrodynamics

The most important features are: (1) the emission and assimilation of nutrient and contaminant non-conservative loads that commonly come from the upstream rural or peri-urban communities discharging poor or non-treated wastewaters; (2) the variable self-purification capability of the active cave system; and (3) the variation

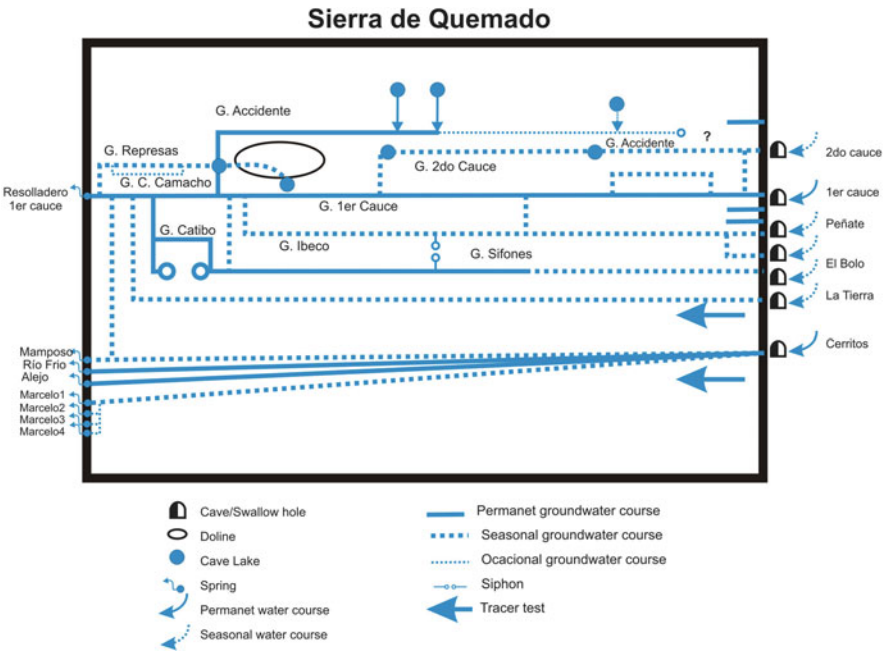

Fig. 16.6 General scheme of the explored and mapped underground connections at the Sierra de Quemado (Farfán et al. 2009)

and variability of the chemical composition of waters due to the residence time in the aquifer, the mixing length and the contact time rock-water.

16.4.4 The Local Level of Social and Economic Development

The local society is developed as a rural low-income community concentrated upstream of the absorbent slope and dispersed downstream of the discharge slope. No population lives in the Sierra de Quemado strictly. Water demand is insufficiently satisfied and domestic wastewater has practically no treatment (Fig. 16.6).

16.4.5 The Social and Natural Vulnerability and Hydrologic Risks

Social vulnerability and natural risks are more evident in the emissive (discharge) slope because of the dispersion of the population, the occupational framework and the types of housing (Molerio 2004b). Water demand is satisfied individually by familiar collection, and storage is not supervised by health activities. This led to generally insufficient water supply and to a low drinking water quality. That is not the case of the

Community of El Moncada, which is a system of municipal water supply although not very efficient operated. Isabel Maria is the most vulnerable community to water quality deterioration, but not to flood events. In this case El Moncada is more vulnerable because under certain conditions the cave system does not have enough capability to evacuate the floodwaters, and backflow could reach the community (as it has occurred during some hurricanes).

16.5 Conclusions

The effectiveness of any instrument of environmental management has to be founded in the adequate knowledge of the system where it will be applied. The following knowledge instruments should be taken into account:

- The laws governing the organization of the surface runoff.
- The local development of the hydrological karst system
- The physical and biogeochemical hydrodynamics.
- The local level of social and economic development
- The social and natural vulnerability and hydrologic risks.

The main vulnerability to contamination is located at the emissive slope and the most important stress comes from horizontal flows. No human stress is identified in the top of the hills, but in the slopes.

Well-integrated cave (flow) systems contribute to the improvement of input waters of low quality in terms of Dissolved Oxygen. On the other hand, low meandering and/or integrated systems do not produce any improvement in water quality and constitute a strong hazard to the communities living at the discharge slope.

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