Living with Pseudokarst

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Abstract

Urbanization is rapidly increasing in some sparsely inhabited "substandard" subdivisions on Hawaiian pseudokarst. Because of conduit flow of groundwater in lava tubes and lava tube caves, an increasing threat of contamination and pollution exists. Yet conduit flow of water in such pseudokarsts is omitted from conceptual diagrams and models of local hydrology and dye tracing is an alien concept.

The extent of the problem in Hawaii is unknown. In Terceira (Azores, Portugal) much of the water supply of a sizeable town is obtained from conduit flow through a lava tube cave; municipal water works have been constructed in the cave. A "boiling" freshwater spring in the harbor of Hilo, Hawaii, is among several phenomena suggesting similar flow. Some Hawaiian lava tube caves contain still-water clay deposits; others have sorted to unsorted heterogenous streamfill. Thus, both steady state and flood pulse flow must be considered.

Kaumana Cave is suggested as a model site for study. It contains garbage dumps including automotive wastes and pesticide containers in an area that periodically floods to the ceiling. The resurgence of its floodwaters is unknown, and input and output through various feeder cracks is highly dependent on volume of rainfall. A piping conduit may exist beneath the cave.

Introduction

Public health aspects of groundwater flow in karstic conduits are a common topic at national cave and karst management symposia. Recent investigations in Hawaii and elsewhere indicate that conduit groundwater flow in volcanic pseudokarsts is a cause for similar concern. This is contrary to conventional wisdom, that is, that the flow of lava tube caves is flowing lava, not flowing water (Halliday, accepted for publication). Even a notably authoritative recent overview of groundwater tracer dyes merely commented that "dye transport has apparently occurred both through fractures and through paleosoil zones (in basaltic lava flows)" (Aley, 1997).

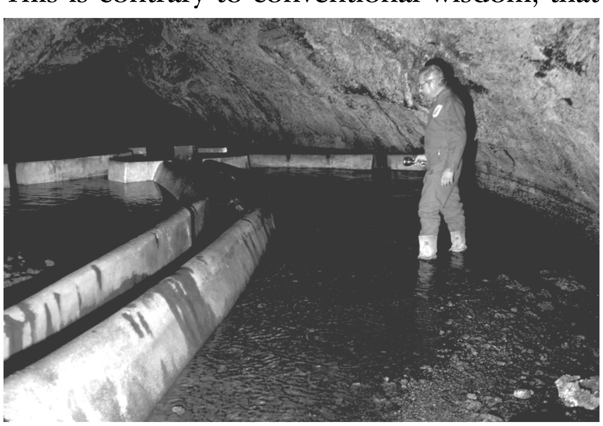

Figure 1. Municipal waterworks in a lava tube cave on Terceira, Azores. Photo by author.

This mindset has been universal, however. Long ago, the noted geologist James A. Dana noted the essential nature of volcanic pseudokarst, with water "to be found only in caves" (Dana, 1849). Decades ago on the island of Terceira (Azores, Portugal), municipal waterworks were constructed in a lava tube stream cave which drains a small caldera (Figure 1). In Mauritius, "Womens' Washing Cave" is at the downslope end of a pseudokarstic window. In both Utah and Hawaii, local ranchers have dammed streams in lava tube caves for domestic and livestock use.

Stream Downcutting Into Lava Tube Caves

Only a moment's reflection is needed to recognize that ordinary stream downcutting across the course of a lava tube cave will channel streamflow into the cave it intersects. Further, that the tubular downslope pattern characteristic of lava tube caves may be even more conductive to conduit flow of water than that of karstic caves.

In volcanic pseudokarsts, surface streams tend to sink into cracks before they have an opportunity to cut down into lava tube caves but increasing numbers of examples of downcutting piracy into lava tube caves now are on record. Perhaps the most spectacular is in the headwaters of the Rogue River, Oregon, USA (Figure 2). In Hawaii, the upper level of well-known Turtle Cave (Kau District, Hawaii County) is truncated by downcutting by a stream which crossed it diagonally. Its lower level contains extensively sorted deposits of a typical turbulent stream.

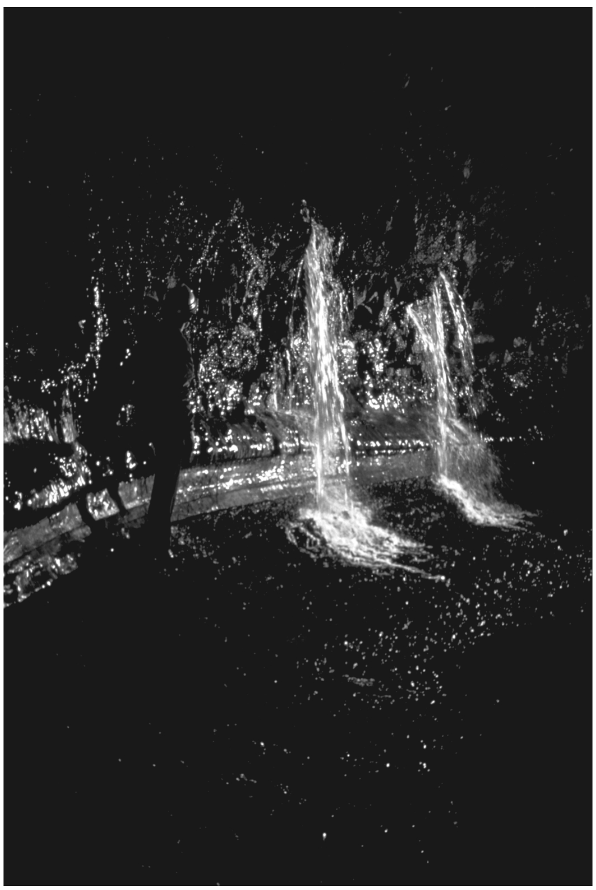

Figure 2. Piracy by downcutting of the Rogue River into a lava tube cave, Oregon, USA. Photo by author.

Downslope Lava Tube Swallets

Numerous other lava tube caves in Hawaii, Korea, and elsewhere contain sorted or unsorted stream or pond deposits resulting from surface water naturally channeled into a preexisting cave entrance. Some of these have been incised subsequently by downcutting within the cave. Near Hilo, Hawaii, Pukamaui is a lava tube cave opening on the bank of the Wailuku River on the northeast edge of a very large pseudokarstic complex. Until it was walled up, this cave periodically captured much of the water supply of Hilo (Stearns and Macdonald, 1946). The lower kilometer of Ape Cave, Mount Saint Helens, Washington, USA, contains two successive tephra "mudflow" deposits from an eruption about 1,800 years before present; each is about one meter thick. Nearby, some smaller caves carry snow runoff. A few served as conduits for tephra "mudflows" after the 1980 eruptions and at least one "mud resurgence" was observed.

Hawaiian Pseudokarsts and Their Significance

More than 9,000 square kilometers of "the Big Island" of Hawaii consists of a complex of volcanic pseudokarsts. One consists largely of the Ailaau Flow Field of Kilauea Volcano, mostly 300 to 500 years old. It contains Kazumura Cave (the world's longest known lava tube cave) and many others. In this large pseudokarst, a total of about 100 kilometers of cave passages has been mapped to date, with much remaining. It is generally considered the world's leading area for the study of lava tube caves. Other speleoiferous pseudokarsts exist on Mauna Loa and other volcanos throughout Hawaii. On the islands of Mau and Oahu, tunnels drilled to tap perched bodies of water incidentally intersected lava tube caves with running streams at considerable depth.

The Ailaau Flow Field Pseudokarst is close to the city of Hilo, and is the location of increasingly populated "substandard" subdivisions, which lack city water, sewers, and other normal infrastructure. Some wells exist, but most homes depend on rooftop water catchment. Many homes lack even septic tank disposal, with pipes conducting raw sewage directly into cracks and lava tube caves. An even denser population with a more fully developed infrastructure lives atop a narrow tongue of pseudokarst funneling downslope into the city of Hilo from the northeast side of Mauna Loa volcano.

The most recent flow here (containing Kaumana and some smaller caves) was in 1881. Nearby caves in older flows are know to extend down to sea level in Hilo. So do other caves in the town of Kailua-Kona on the other side of the island.

Figure 3. Garbage dump in Kaumana Cave, Hawaii. Photo by author.

Unlawful Disposal in Hawaiian Lava Tube Caves

Large dumps of unlawful waste exist in Kazumura Cave, Kaumana Cave, Lower Uilani Cave, and others throughout Hawaii. Automobile wastes are especially conspicuous, but partially emptied pesticide cans and medical wastes also have been identified. The garbage dumps in Kaumana Cave are especially troubling. Multiple dumpsites containing pesticide cans and medical wastes are present in a section which floods to the ceiling, and floodwaters have distributed some of the waste downflow. Further, raw sewage has been reported in a remoter section of the cave beneath Kaumana Village (an up-slope suburb of Hilo), as in several other "Big Island" lava tube caves. During extreme flood pulses, groundwater bursts from the lower entrance of this cave and invades a subdivision built atop what was once the lower 500 meters of the cave. At other times, the resurgence of its floodwaters is unknown.

Basic Hydrogeology of Hawaii Island Pseudokarsts

Several recent investigations indicate that the volcanic pseudokarst of Hawaii diverge considerably from the traditional Ghyben-Herzberg freshwater lens concept (Izuka and Gingerich, 1998; Fischer *et al.*, 1966; George Wilkins, quoted in Hastings, 1989; Smith, 1999; Doty, 1980 *et al.*). Where no conduit exists, the porosity of various volcanic beds results in considerable compliance with this model. Several types of impervious structures, however, form local barriers to groundwater flow, both horizontally and vertically. Especially important horizontal barriers are dense, unfractured expanses of pahoehoe basalt with effects somewhat comparable to those of chert, shale, and sandstone layers in limestones. As for vertical or steeply tilted barriers, more or less impermeable dikes trap discrete bodies of meteoric water on the flanks of various volcanos. All these structures are unrelated to conduit flow unless piping has occurred long the upper surface of dense pahoehoe basalt. The islands are tectonically and isostatically active, however. Cracks up to one or two meters wide are locally very important in directing and expediting underground flow at velocities approaching those of conduit flow. Comparatively small tectonic cracks serve as feeders and drains for streams in lava tubes.

Further complexity in groundwater flow on the Big Island is evidenced by two major confined aquifers of considerable thickness. Both conduct large volumes of rainfall from points high on Mauna Loa volcano. They extend downslope beneath Hilo and some of its southern suburbs to deep, ill-defined submarine resurgences. The lowermost was discovered only recently, at a depth of nearly 300 meters. When it was intersected by a test well, hydrostatic pressure caused an artesian flow of 10,000 liters/minute (Smith, 1999). The degree of missing of groundwater carried in lava tube conduits with these deep aquifers is unknown.

Basal springs of Hawaii Island especially diverge from the simple Ghyben-Herzberg lens model. Instead of diffuse resurgence at sea level, bubbling springs are numerous (Stearns and Macdonald, 1946). Many discrete freshwater plumes extend seaward atop the ocean, as far as 400 meters (Fischer *et al.*, 1966). Some comparatively small plumes are approximately aligned with Kaumana Cave, but much larger resurgences exist about one kilometer farther south, in the Waiakea Pond-Wailoa Stream complex. This complex discharges approximately 500 million liters/day into one section of Hilo Bay—a first magnitude spring. In its outer channel is a large upwelling "boil" of water, which appears to emerge from the mouth of a conduit of some type. Also impressive is Ninole Springs at Punaluu, downslope from a speleoliferous pseudokarst of Mauna Loa volcano. This spring complex is estimated to have a discharge of 60 to 75 million liters/day (Martin and Pierce, 1919). Here, the largest springs emerge from lava tubes (Stearns and Clark, 1930; Stearns and Macdonald, 1946). At sea level, discharges downslope from the Ailaau pseudokarst, volumetric estimates are more difficult, but large volumes clearly resurge here also. It is surprising that conceptual diagrams and models of regional hydrogeology omit lava tube and other conduit forms of groundwater flow. References to dye tracing here apparently are nonexistent.

Hydrology of Kaumana Cave

Kaumana Cave is an extensive, largely unitary lava tube cave located on a moderate slope in the upland suburbs of Hilo. About 2,200 meters have been mapped to date. An additional 500-meter section is known to have been destroyed by subdivision construction downslope from Edita Street. Considerably more cave exists upslope from the mapped section, partly underlying Kaumana Village. Raw sewage has been reported entering this section of the cave. Much as in the case of dendritic karstic cave systems, still farther upslope is a recharge area, typical in the ohia rainforest at this elevation (Doty, 1980). In the upper end of the mapped section, floatable debris is stuck to the ceiling, indicating extensive flooding of this part of the cave. In a roomier area just downslope from this area, running water often is heard just beneath the apparent floor of the cave. A piping cave like Christmas Canyon Cave, Mount Saint Helens, Washington may exist here.

During heavy rainfall (10 to 12 centimeter/day for three days) several small waterfalls jet out into the cave passage two to three meters above the floor. They are located a few hundred feet downslope from the section which floods completely. They spurt into the cave through cracks in its accreted lining, and appear to emerge from a perched aquifer incised by the lava flow containing the cave. They form a shallow stream which flows downslope for about 300 meters, passing beneath the main entrance sink through a lower level passage formed by a secondary ceiling. Its flow is augmented by smaller insurgences through other cracks, near floor level. Loss into other cracks diminishes its volume and, except during maximum flood pulses, it finally disappears into the cave's floor. Similar augmentation and loss through tectonic cracks have been observed and photographed in Mauritius and in Utah. Except for the maximum flood pulses mentioned above, resurgences of this stream are unknown.

Figure 4. Waterfalls, Kaumana Cave, Hawaii. Photo by author.

Significance of Conduit Flow in Hawaiian Lava Tube Caves

In the drier parts of Hawaii Island, conduit flow in lava tube caves some day may provide significant municipal or agricultural supplies of water. Deep confined acquifers, however, currently appear more promising for these. The present focus, therefore, is on public health aspects of conduit flow—just as in the case of similar flow in karsts.

It thus is obvious that unlawful disposal sites and raw sewage are potential threats to ground water quality in parts of Hawaii Island. Also it is obvious that these threats will increase with increasing population density in certain pseudokarstic areas unless present practices are altered drastically. But it is not certain that these practices are actually causing unacceptable harm to Big Island residents. Nor is it certain that even today's uncontrolled population growth will inevitably impact groundwater quality to an unacceptable level. The dilution fact in the Ailaau pseudokarst and the Mauna Loa deep aquifers is enormous. Admittedly, Hilo Bay is polluted, and swimming is discouraged. Where swimming is common in other freshwater plumes such as Ninole Springs, there are anecdotal reports of a high incidence of otitis externa and its complications. But the incidence of leptospirosis actually seems to be lower from well water than from rooftop catchment. Perhaps it is fortunate, however, that the apparent drainage of the Aillaau pseudokarst is to a section of coast unsuitable for swimming and lacking in wells.

Management of Conduit Flow in Big Island Pseudokarsts

The usual laws for the protection of groundwater exist in Hawaii, but the General Plan for Hawaii County (1990) does not include protection of groundwater (nor caves) and these laws are generally unenforced.

The Hawaii Chapter of the National Speleological Society has proposed two approaches to this problem. On one hand, it has proposed a series of new provisions in the 2000-2009 General Plan. These new sections would provide a priority for protection of caves, pseudokarst, and groundwater, with zero tolerance of raw sewage and toxic and hazardous wastes. Further, it has proposed a conference to bring together human resources in the relevant fields to clarify actual threats to public health and to recommend solutions.

In September 1999 the Commission on Volcanic Caves of the International Union of Speleology commended the Hawaii Chapter for its leadership in this important area.

Conclusions

Conduit flow of water in some volcanic pseudokarsts differs only quantitatively from that in karstic terrains and has the same public health implications. Studies of types long established in karstic terrain need to be implemented in large areas of Hawaii. Both steady state and flood pulse flow must be considered. Titles of symposia on management of caves and karst should be expanded to include this additional area of concern.

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