

RAW SEWAGE AND SOLID WASTE DUMPS IN LAVA TUBE CAVES OF HAWAII ISLAND

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Lava tubes on the island of Hawaii (and elsewhere) are possible subsurface point sources of contamination in addition to more readily identifiable sources on the surface. Human and animal waste, and hazardous and toxic substances dumped into lava tube caves are subject to rapid transport during flood events, which are the dominant type of groundwater flow through Hawaiian lava tubes. Although these waste materials may not be a major source of pollution when compared with some surface sources, this potential hazard should be evaluated much as in the case of karstic floodwater conduits.

This paper explores the interaction of water flow and solid waste dumps and sewage in lava tubes and lava tube caves of Hawaii Island, Hawaii - an island almost as large as the state of Connecticut (Fig. 1)-and resulting potential threats to groundwater quality. In recent years, Hawaiian cavers and speleologists have become increasingly concerned about these occurrences. Some of the solid waste dumps can be seen to contain partially empty containers of toxic and/or hazardous substances (Fig. 2), including automotive and agricultural waste. Stinking raw sewage speaks for itself (Fig. 3), and members of the Hawaii chapter of the National Speleological Society have been shown the top of a septic tank or cesspool near Keaau said to consist of an unlined segment of lava tube cave. The subject is especially controversial because no known case of human death or illness has been traced to any of these cave sites, and no toxic level of harmful chemical is known to have been identified in local drinking water sources. Further, no one has attributed current pollution of Hilo Bay and decimation of the island's marine fisheries to these sources. Consequently, these practices traditionally have been condoned regardless of federal, state, and local laws and regulations.

OVERVIEW OF LAVA TUBES AS GROUNDWATER CONDUITS

Perhaps thinking of the now infamous "natural sewers" beneath Bowling Green, Kentucky, and other classical American karsts, Palmer (1946) wrote that "lava tubes (on the island of Oahu - W.R.H.) would be as good as artificial pipes, but they are far from common". More recently an enthusiastic journalist wrote that "when rain falls on the Big Island (Hawaii Island - WRH), it apparently collects in lava tubes and is whooshed down to the sea..." (Hastings 1989). Neither assertion was correct, but both contained important insights. In some parts of the world, lava tube caves function full-time as conduits for stream flow. In Oregon, a vigorous headwater of the Rogue River flows through a lava tube cave more than 100 m long (Fig. 4). On the volcanic island of Terceira (Azores, Portugal), spelean waterworks capture year-round stream flow to serve a town (Fig. 5). The stream in Utah's Duck Creek Lava Tube has been dammed to supply a local ranch. Other

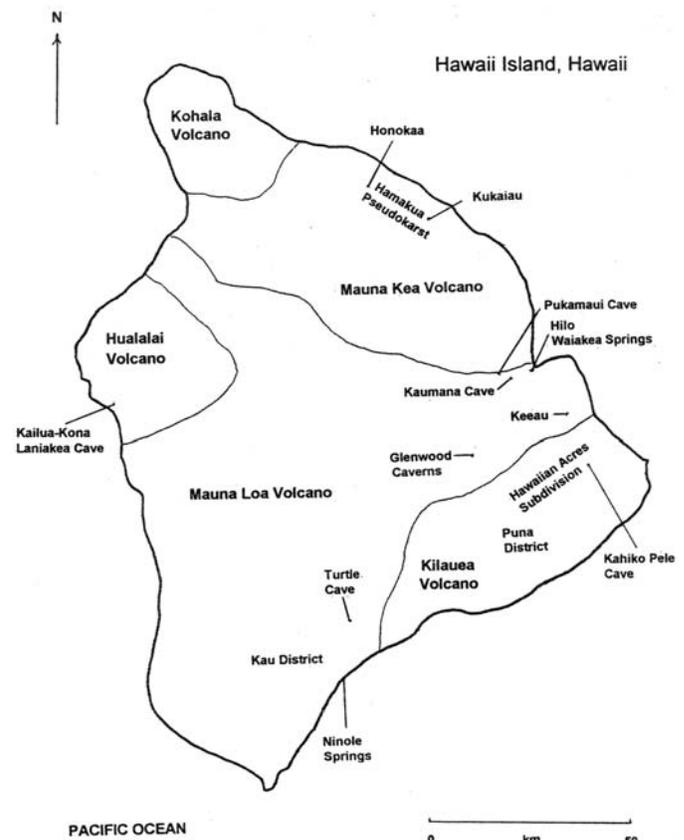


Figure 1. Map, Hawaii Island.

examples are reported in volcanic terrain from Madagascar and Tahiti to Iceland. Beneath a layer of kaolinized volcanic ash on Mauna Loa volcano on the island of Hawaii, a stream up to 0.6 m deep flows in Glenwood Caverns, but only about half the year (Halliday 2001). Even standing freshwater bodies are largely lacking in Hawaiian lava tube caves. Aside from a few at sea level where basal fresh water floats on sea water in highly permeable volcanic rocks that include the caves, only a single small perched pond is on record for the entire island - the pond in the lower cave near Kuka'iaiu (Stearns & Macdonald 1946).



Figure 2. Incompletely drained containers of pesticides, herbicides, and other agricultural and automotive chemicals dumped in Kaumana Cave.



Figure 3. Looking diagonally upward to a pipe connected directly to a toilet in north Puna District, near Keaau. A pile of moist feces was present beneath the pipe.



Figure 4. Spring runoff passing through a lava tube cave in the headwaters of the Rogue River, Oregon.

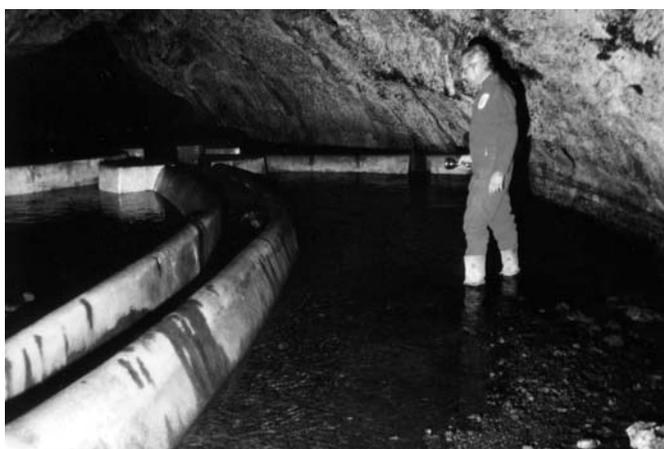
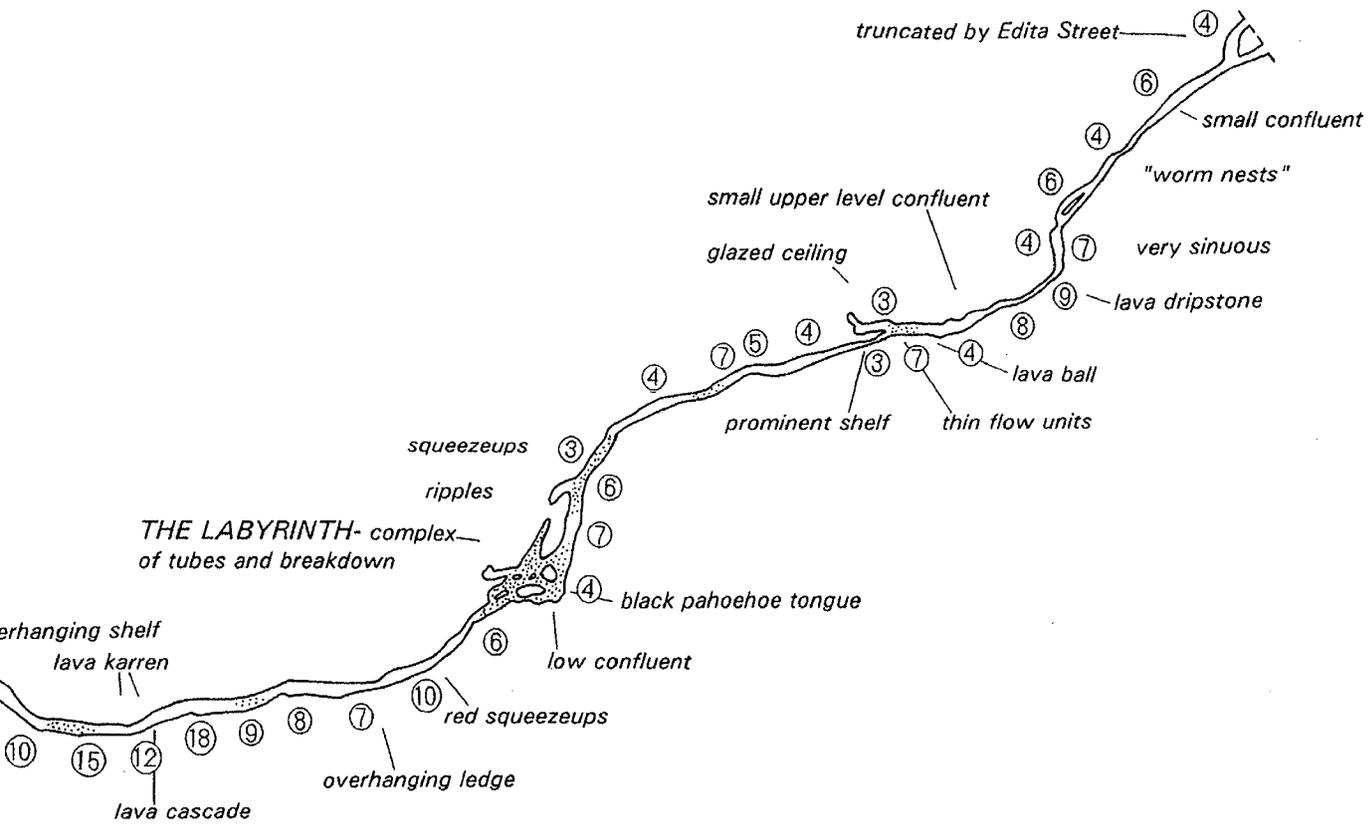


Figure 5. Artificial channeling of groundwater flow in a lava tube cave on the island of Terceira, Azores, Portugal, for domestic purposes.

PUBLISHED STATEMENTS ABOUT HAWAIIAN LAVA TUBES AS WATER CONDUITS

Stearns and Clark (1930) may have begun the discussion of Hawaiian lava tubes as water conduits: "Such systems of tubes, of which there are literally thousands in the Kau District, of course offer free passage to ground water". They reported observing fresh water emerging from lava tubes at the huge Ninole Springs complex, a statement later repeated by Stearns and Macdonald (1946). Unfortunately, this appears to have been conjecture. It is true that there are thousands of lava tubes in the Kau District (nearly all are only a few centimeters in diameter) but at Ninole Springs, no one else seems to have observed any lava tube resurgences and none are seen today. They also mentioned brackish water in once celebrated Laniakea Cave, near the shore in downtown Kailua-Kona. But they evidently considered these to be mere isolated curiosities rather than inherent parts of the groundwater transport system

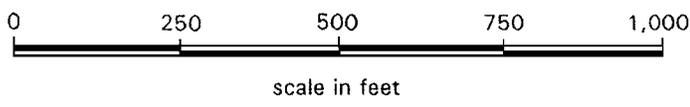


lava ball
 entrance puka
 not shown

7
 general slope

KAUMANA CAVE

HAWAII COUNTY, HAWAII
 SISTECO COMPASS AND CLOTH TAPE
 SURVEY BY THE HAWAII SPELEOLOGICAL
 SURVEY
 1993-1996
 7,210 feet shown



of volcanic pseudokarsts. In discussing first-order Waiakea Springs in downtown Hilo, they did not consider any of the lava tube caves in that city, and evidently they knew nothing of the lengthy caves upslope from other large springs along the coast near Keaau.

Macdonald and Abbott (1970) briefly mentioned water flow in lava tube caves but omitted it from their conceptual diagrams. In the revised second edition (Macdonald *et al.* 1983, p. 283) a photograph shows water gushing from a small lava tube cave, but even the minimal 1970 text was omitted. The multivolume Geological Society of America overview of American geology (Hunt *et al.* 1980) mentioned lava tubes as mostly "less than a meter in diameter and of small lateral extent", with a maximum length of "several km". Kazumura Cave actually has 65.6 km mapped at present (K. & C. Allred, pers. comm. 2001). These writers were the first to include a lava tube in a conceptual diagram of water flow in Hawaii. However, they minimized the roles of lava tubes in groundwater flow by grouping them with joints, cracks, rubble, clinker beds, and waterflow voids together producing a "hydraulic conductivity of a few hundred to a few thousand meters per day". Aley (1997) mentioned no water flow through lava tubes of any size: "through basaltic lava flows; dye transport has apparently occurred (only) through fractures and through paleosoil zones."

Stearns and Macdonald (1946) recorded 2 important phenomena on Hawaii Island. One was a spectacular floodwater diversion of the Wailuku River through Pukamaui Cave; the cave had to be walled up to return Hilo's principal water source to its normal intake. The other consisted of 2 lava tube caves near Kuka'iau in the Hamakua pseudokarst on Mauna Kea Volcano. They perceived these as a swallet cave and a seasonal resurgence cave in a conduit system. The lower cave is the site of the perched pond mentioned above. The other is a swallet only seasonally but has extraordinary erosional and depositional features discussed below.

COMPARISON BETWEEN KARSTIC AND LAVA TUBE CONDUITS

Unless directly fed by surface streams, lava tube caves generally carry a smaller and less significant proportion of groundwater flow than do their karstic analogues. Under certain circumstances, however, their flow is disproportionately important. Basal groundwater may flow freely for dozens of meters in lava tubes near sea level. Tubes associated with significant aquacludes (e.g., kaolinized volcanic ash, paleosols, unfractured basalt, etc.) may carry perched streams for hundreds of meters and much more in times of flood. Beneath a suburb of Hilo, Kaumana Cave is an example of a lava tube cave that carries floodwater for more than 1 km.

Above the water table, lava tubes function as "leaky pipes". Through large and small cracks, water leaks in and out of tubes, depending on saturation of extensive interconnected extratubal spaces that function as potential reservoirs. In addition to cracks, these include spaces within aa lava, volcanic

breccia and rubble, and various other small cavities. They vary markedly in lateral extent and in depth to the water table or to aquacludes, and evidently also in their rate of percolation.

On much of the island of Hawaii, these reservoir spaces permit year round, near vertical percolation for dozens or hundreds of meters. Those adjoining a lava tube less than 0.5 m in diameter on Kohala volcano are typical. Here, seemingly unlimited quantities of surplus water from an irrigation ditch are absorbed by this small tube, whence it leaks rapidly into the reservoir space. In the latter, it evidently percolates nearly vertically to the basal water table without spillover or intermediate resurgence (S. Bowen, pers. comm. 2000). Such reservoir spaces provide a large but necessarily limited dilution factor for fecal bacteria and toxic chemicals, and also a very large surface area for adsorption of some of the latter. In Hawaii Island, groundwater conduit flow is almost exclusively a floodwater phenomenon. Effective conduit flow occurs only where water flow overwhelms crevices in the "leaky pipe" and/or saturates the immediate peritubal reservoir space. This occurs especially where lava tubes are located close to basal groundwater or to an underlying aquaclude. Natural and artificial channelization of surface runoff (e.g., pirated stream gullies, roadside drainage ditches, etc.) may be major contributing factors.

WATER FLOW IN AND BENEATH KAUMANA CAVE

Located beneath a suburb of the city of Hilo, Kaumana Cave is an especially well known example (Fig. 6). Its main entrance section is the principal feature of Kaumana Caves County Park and is much visited. The lower 2.2 km of this cave (from Kilua Road to Edita Street) lacks streamflow unless rainfall exceeds ~20 cm within a period of 2-3 days: a common occurrence in all seasons. Stone (1992) has graphically described local flooding and fecal contamination in various parts of the cave that extend several kilometers upslope from Kilua Road. All known parts of the cave vary so markedly in shape and size that numerical estimates of streamflow discharge are challenging. No instrumental measurements are on record. It is visited so frequently, however, that numerous observations document location and general magnitude of streamflow under varying meteorological conditions.

The lower end of Kaumana Cave opens into a drainage ditch several meters below the roadway of Edita Street. Both the ditch and the street are at right angles to the cave. This street is the up slope margin of a 1960s subdivision built atop a section of the cave ~0.8 km long, now segmented and obstructed by the roadway. At least once in the 1970s, floodwaters emerged from its lower entrance and overflowed Edita Street and part of the subdivision (Stone 1992).

This cave has been mapped several times, but only as far as Kilua Street where garbage becomes daunting (Fig. 7). In periods of normal rainfall, running water sometimes is audible beneath the floor of this section of the cave. Rainfalls of 20-30 cm produce waterfalls spouting from cracks high on the wall



Figure 7. Part of the largest solid waste dump in Kaumana Cave, located in a suburb of Hilo, Hawaii.

of one cave section (Fig. 8). They form a small stream that runs on or just beneath the floor for several hundred meters before finally sinking into cracks. Its flow is augmented by several small bubbling springs at or just above floor level and part of its flow also is lost into small floor-level cracks.

During a record-breaking flood in November 2000, this cave overflowed through a ceiling orifice located in the gutter of Uhaloa Street upslope from the mapped section (Fig. 9), perhaps forcing a new opening at the edge of a metal plate embedded in the roadway at the site of a previous breakout 3-4 m above floor level.

The cave's best-known garbage dump is located just downslope from Kilua Street, on State of Hawaii property. Partially emptied containers of hazardous and/or toxic waste are present (Fig. 2). Torrential rains of November 2000 compacted and partially distributed this dump down tube (Halliday 2001). Worn-out tires were washed more than 100 m to a point where they piled up against a rocky obstacle (Fig. 10). Smaller solid objects were washed up and over this obstacle and were jammed beneath rocks in the next chamber. Floatable waste



Figure 8. In addition to floodwaters which briefly fill much or all of Kaumana Cave, moderate rains cause episodic waterfalls two to three m high, spouting from the walls of the cave.



Figure 9. January 2001 photograph of overflow point of Kaumana Cave, in Kaumana community resulting from November 2000 flood. The location is the site of a former opening of the cave which was bridged to permit road construction.

hung on projections up to 3 m above the floor at points much farther down the cave.

The ultimate resurgence of Kaumana Cave floodwaters is unknown. Hilo's first-order Waiakea Springs are ~7 km downslope. No dye traces are on record. Hilo Bay is so polluted that swimming is prohibited, but shoreline fishing for family consumption is a popular hobby.

CONDUIT FLOW IN OTHER HAWAII ISLAND CAVES

Clear evidence of flooding is present in several other caves on this island. The Hamakua pseudokarst on the well-watered windward slope of Mauna Kea volcano contains several caves in Hamakua volcanic rocks: The oldest tube-forming lavas known on Hawaii Island (Wolfe *et al.* 1997). A lava tube cave in Honokaa opens at the lower end of a narrow lava trench containing large accumulations of solid waste which is swept into the cave by periodic floods. This cave also smells of raw sewage, at least intermittently (M.S. Werner, pers. comm., 1998). Another lava tube cave in this town long served as an open sewer for a hospital and several churches and business establishments (ParEn 1990); its present status is unknown. Farther upslope are several seasonal swallet caves and a few seasonal resurgence caves. Most of them demonstrate extensive erosion of accreted tube linings together with accumulated sediments ranging from rounded boulders >0.5 m in diameter to multilayered mud. The larger of the 2 caves near Kuka'iaua is so heavily eroded that some well-reputed investigators have found no evidence that it originally was a lava tube, and consider it purely erosional (Kempe *et al.* 2001).

In North Kona District, upslope from Kailua-Kona, the name of Gomes Flashflood Cave is self-explanatory. Entry requires crawling through a large pile of stream-wedged branches and small trees, hung up at the low entrance. Inside, mud banks up to 1 m high have been eroded into long, tapered forms. In Kau District, the downslope end of well-known Turtle Cave has been eroded away by a surface stream that downcut a deep, narrow gully diagonally across the cave. About 100 m of this level was backflooded in November 2000, with several centimeters of mud and floatable debris deposited almost to the famous "turtle", a lavaball partially "submerged" in the smooth pahoehoe floor of the cave (Halliday 2001). This cave also has a lower level with a covert orifice somewhere in the streambed, capable of passing large stream cobbles as well as smaller clastic material. Before the 2000 flood, the lower end of this passage was notable for mud deposits up to 2 m above the floor, and the ceilings of its unmapped terminal branches sloped down to thick accumulations of watery mud on their floors. This appearance was unchanged after the 2000 flood. Elsewhere in this passage, newly-sorted stream sediments appeared to be located in the same positions as their counterparts before the flood. Back-filling was much less pronounced than in the upper passage.

In Puna District, Kahiko Pele Cave is the final swallet of an artificial channel for intermittent floodwaters; its floor sedi-

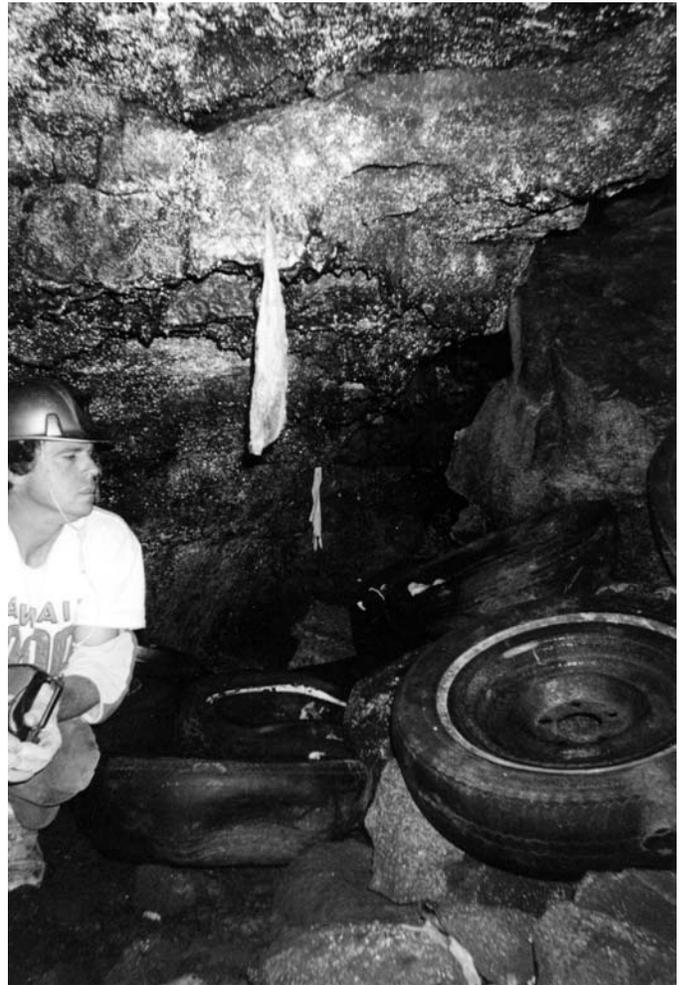


Figure 10. High velocity floodwaters washed these abandoned tires about 100 m down-cave from the main garbage dump in Kaumana Cave in November 2000. Here they were stopped by a pile of fallen rock. Lighter material from this dump was washed up and over this rockpile and was found at downslope points up to 3 m above the cave's floor.

ments are almost entirely mud. This small cave is of particular concern because of the partially emptied pesticide containers found in it.

SIGNIFICANCE

Present data indicate that, by today's standards, Hawaii Island drinking water sources are not at risk from floodwater dissemination of lava tube contaminants. Nationally, a trend is evident toward stricter standards for water quality, and each year, additional chemicals are added to the list that must be monitored.

Further, populations on large cavernous pahoehoe lava flows (rheogenic pseudokarsts) such as Hawaiian Acres Subdivision are increasing rapidly. In rainy Puna District, part of their need for domestic water can be met by rooftop catch-

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ment despite the risk of leptospirosis. But, additional subsurface water sources will be needed in the near future, and they will have to be located away from plumes of groundwater contamination.

Potentially alarming solid waste dumps on Hawaii Island are not limited to lava tube caves, and much of the island's sewage goes directly to groundwater through crevices rather than through lava tube caves. Some Hawaii Island floods are so overwhelming that lava tubes carry only a small portion of their total contaminant load. When pollution or contamination is identified in drinking water or in marine fisheries, or impairs beach recreation, remediation far beyond the island's lava tubes will be needed. Lava tubes containing unlawful sewage and solid waste, however, are prominent among the identifiable points to which relevant laws and regulations can be applied readily. Even now, they are obvious sites for cleanup efforts.

On August 2, 2000, the Hawaii Chapter of the National Speleological Society convened a Hawaiian Conference on Lava Tubes and Ground Water. In followup, the Safe Drinking Water Branch of the Hawaii State Department of Health has begun tabulating and documenting cave dumps on Hawaii Island, looking toward funding cleanup activities on state lands. All sewage and solid waste dumps in caves on this island, and elsewhere in Hawaii, should be reported to the Hawaii Chapter or the Hawaii Speleological Survey of the National Speleological Society for transmissal to the appropriate state authorities.

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