Chapter 4

Rainwater catchment on Hawai‘i Island

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4.1 INTRODUCTION

Hawai‘i Island is one of the few places in the United States where rainwater catchment is common and necessary. Much of Hawai‘i Island is rural and lacks public utilities including water. Rainwater catchment systems are the most customary alternative. The Rainwater Catchment Program of the University of Hawai‘i was instrumental in enabling catchment owners to understand their water supply risks and how to properly care for their systems in order to improve water quality and quantity. This chapter introduces readers to the unique rainwater collection history and usage of Hawai‘i, and describes the rainwater catchment program of the University of Hawai‘i, how it developed and serviced the residents of the islands. It also discusses challenges such as lack of system standards and water quality threats. The rainwater catchment program grew and even touched international arenas, addressing issues well beyond its humble beginnings.

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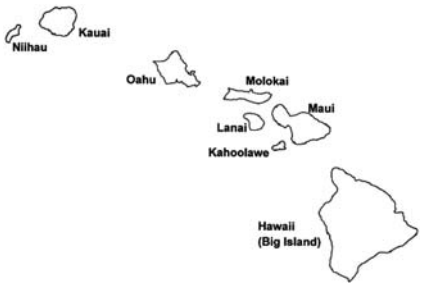

Figure 4.1 Major Hawaiian Islands. (*Source*: HFD, 2008).

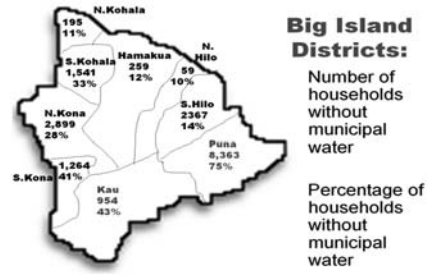

Figure 4.2 Municipal water availability. (*Source*: HFD, 2008).

4.1.1 Introduction to Hawai'i

The USA state of Hawai'i has 8 major islands (Figure 4.1). The islands are volcanic in nature, formed as lava erupted from a 'hot spot' near the middle of the Pacific Tectonic Plate. The largest of the 8 major islands shares its name with the state, so to avoid confusion Hawaii Island is and will henceforth be referred to by its nickname, 'Big Island'.

The current population of the state of Hawaii is approximately 1.4 million. The majority of the population lives on the island of Oahu. The Big Island has a population of 200,983 (U.S. Census Bureau, 2018). It is larger than all the other major islands put together, with 63% of the land mass but only has 14% of the state's population. Much of the island is considered rural and those rural areas are generally lacking public utilities including water. Most of the homes without municipal water are on the south side of the island (Figure 4.2).

Big Island is home to two large mountains (Figure 4.3), nearly 14,000 feet above sea level, and as a result, has very diverse rainfall and weather patterns. While some areas have very low average annual rainfall, the majority of people who harvest rain see an average of 32 to 133 inches of rain a year (Frazier *et al*., 2016).

Figure 4.3 Hilo Bay. Mauna Loa on the left and Mauna Kea half hidden by clouds on the right. Both mountains are close to 14,000 feet above sea level and influence rainfall. (*Source*: Authors).

Figure 4.4 Old redwood tank located in the town of Volcano. (*Source*: Author).

4.1.2 Catchment history

Regular European contact with the islands started in the late 1700's and it was likely that water catchment became popular in the early 1800's. The older water tanks were usually wooden. A few old redwood tanks are still in use (Figure 4.4).

Today, individual homeowners with water catchment systems serving less than 25 people are the responsibility of the owner and there is no government oversight.

Wells exist but are costly and often impractical for a homeowner to dig because much of southern half of the island is made of layers of volcanic rock rather than soil. There is some surface water. Streams that do exist are usually intermittent or quite varied in their flow because the lava rock that makes up the island is so porous. For domestic water, catchment was and remains more practical.

In the 1960's subdivisions were set up as private subdivisions, meaning property owners were responsible for any utilities and/or roads. The subdivisions were often large. The largest is 36.8 square miles consisting of 157 miles of roads and about 11,500 lots averaging 1 acre each (HOVE, 2019). This particular subdivision, Hawaiian Ocean View Estates (HOVE), when full, will accommodate an average of 34,500 residents, without any municipal utilities. People were attracted by the idea they could get affordable land with few regulations other than basic county building codes. The owner had to figure out how to get water and could put in any kind of water system. Regulations for catchment still only require that a catchment system not be in the setback of neighboring properties and not be made of lead components. Only if there are specifics in a person's building plans for a catchment system, does the system have to conform with those specific guidelines. It is entirely up to the owner whether they store water in a horse trough or swimming pool, catch rain from a roof or the cow pasture.

As these water systems were private, public agencies, in particular the State Department of Health, took no responsibility in servicing that population. The result was having no government agency to turn to for accurate information and guidance. As late as the 1980's the Big Island's Department of Health representatives still refused to help individual homeowners with basic catchment water quality questions. That left residents on the Big Island with no one other than commercial vendors, friends or neighbors to advise them about their catchment systems. Today most subdivision lots have access to electricity, which makes rural living much easier. Surprisingly the lack of municipal water does not have a great effect on home prices. Catchment is considered a reasonable and viable alternative, and is sometimes preferred to municipal water. Another great change was within the Department of Health. While not happy about the subdivision being built without water in the first place, they are more responsive to people needing help with their catchment systems.

In spite of the challenges of the rural subdivisions, they are popular for people like first-time homeowners and retirees who can't afford town prices, for people who want space to operate a small business or farm, for those who like privacy and rural living, and more recently for those of greater economic means who want a place where they can build a big home on a large property. Rural single-family homes on catchment are also popular for people receiving county housing subsidies because the subsidy might otherwise only get them a small apartment in town.

4.2 UNIQUENESS OF THE BIG ISLAND CATCHMENT

One of the challenges of addressing water catchment issues on the Big Island is the wide diversity of systems. Since the properties are largely classified as agricultural/residential, rainwater systems can serve greenhouses, fruit and produce farms, livestock, and pets as well as homeowner needs. The communities are also home to churches, schools, community centers and private small businesses that are run from the home. This includes vacation homes (houses rented out for short term stays without an owner in residence), Bed and Breakfast establishments (where owners are in residence), regular rental homes, etc. Where whole towns are dependent on catchment – the town of Volcano for example – you can also add inns, restaurants, public restrooms, laundromats, fire departments, post offices, and so forth. This huge variety of water needs makes rainwater catchment solutions quite broad and diverse. There is also great variation in socio-economic status, age and education, which often defines the available budget.

At one time there was a stigma attached to living in an area without municipal services. As rural subdivisions became more attractive to all socio-economic levels and self-sustainability became popular, perceptions of living on catchment has become increasingly positive.

4.3 REGULATIONS

United States Environmental Protection Agency (EPA) has stringent rules for any water system that supplies water to more than 25 people. These regulations can be expensive and difficult for small businesses, private schools or churches to comply with. Rather than bear the burden, most find it easier and cheaper to pay for potable water to be trucked to their place of business and kept in storage tanks. Rainwater is still caught and used for the non-potable uses and is unregulated by the EPA. One beekeeper, who extracts and bottles honey on his property, uses treated catchment water for his home use and keeps a small tank for trucked-in municipal water for his honey processing. A community center trucks in water for kitchen use and drinking water, but uses catchment for flushing and cleaning. One laundromat collects rain in a small open reservoir for the washing machines after removing sediment. Public awareness of raw water risks has improved significantly in the past twenty years, but there remains a large public educational task.

Some larger facilities undertake the EPA regulations and treat their rainwater to potable-use standards. One of these is the Hawaii Volcanoes National Park which hosted close to 4 million visitors in 2017 (HVNP, 2019). The park not only collects, treats and uses rainwater for all their water needs, they also promote the sustainability of their systems by encouraging visitors to fill their water containers with treated rainwater from their taps (Figure 4.5).

Another large and unique facility following EPA regulations is the Kilauea Military Recreational Camp (Figure 4.6), a separate recreational camp primarily for military families that is within the National Park. It offers 90 one-, two- and three-bedroom cottages and apartments, dormitories, a restaurant, laundry, snack bars, theater, church, meeting rooms and catering (KMC, 2019). Rain is collected

Figure 4.5 National Park sign promoting the use of rainwater. (*Source*: Authors).

Figure 4.6 The entrance to Kilauea Military Camp.

Figure 4.7 A few of the larger potable water storage tanks for Kilauea Military Recreational Camp.

from a large roof surface designed specifically as a catchment surface and from the roofs of almost all the facility buildings. In total, they have about 6 acres of catchment surface area. For every inch of rain, they can collect about 166,000 gallons of water. The rainfall average is 65 inches per year. There are almost 3.5 million gallons of water storage available (Figure 4.7), and about 20,000 gallons of water are used per day. Rather than treating all the tanks to potable standards, only about 560,000 gallons of storage is for treated potable water. Other tanks have dedicated, non-potable uses such as firefighting, cleaning, laundry, etc., and therefore do not need to be treated to EPA standards (KMC, 2007).

4.4 WATER QUALITY

In 1981, a young woman bought her first home, a rural single-family home in southern Hawaii. The home's water tank was a portable, above-ground swimming pool with a soft permeable cover drooping into the water (Figure 4.8). The dragon flies were enjoying their artificial pond in the sagging center and the algae enjoyed a lovely bloom both outside and inside the tank.

Figure 4.8 Permeable ground cover cloth commonly used as tank cover. (*Source*: Authors).

With some concern, the woman called the Department of Health office on the Big Island and asked if there was something she should be doing to insure her water quality. One 20 micron sediment filter at the point of entry was the extent of her water treatment. The Department of Health agent told her that catchment systems were private and therefore not their responsibility. They made no suggestions or recommendations. Unaware of water quality issues, she spoke to friends and neighbors. The advice they gave her was: 'If the algae or plants growing in the tank are green, then the water is fine. You only have to worry if they start to turn brown'. Everyone else she spoke to, including store clerks selling filters, told her that 20–30 micron filters were all you needed, and that indeed seemed to be what everyone else that she spoke to was using. There were a few people buying drinking water but the general opinion was that it was just a taste preference and not really necessary.

When addressing rainwater quality issues, particularly when the water user is having problems, one has to evaluate a lot of variables. Even within a single subdivision there are micro climates. There can be huge variations in vegetation, (which can add a habitat or source of contaminants), socio-economic factors, education, legal requirements and treatment options. Of primary concerns are bacterial contaminates, for example *Salmonella* (an ingestion hazard carried by reptiles and birds) or *Leptospira* (an ingestion and contact hazard from mammal urine); *Protozoa*, such as *Giardia lamblia* (an ingestion hazard from feces of infected animals); parasitic worms such as *Angiostrongylus cantonensis* that causes rat lungworm disease (an ingestion hazard and possibly contact hazard); and chemical toxins. Viruses have not been observed to be a problem here yet but could be an issue in the future as exotic invasive species continue to arrive on the island.

Socio-economic status can effect what a homeowner can afford to do in terms of treatment. For example unlimited funds will buy a good whole-house treatment system with automatic reminders to change filters or monitor water levels. However, many of lesser means must find more cost-effective solutions. The central issue with treatment is people suddenly finding themselves as sole overseers of a critical system that they really don't understand, with risk factors they have never had to take into consideration. Even people who grew up on catchment can be misinformed and/or complacent about maintenance and treatment.

Rural Big Island often appeals to people with an independent spirit who like living semi-independent of government services. They often get quite inventive with treatment designs and water systems. Some are quite clever, for example using nylon hose for pre-tank large-sediment filters. Others can be misguided, such as the man who used rainwater to fill a pool used for swimming. He then used the same swimming water for his domestic supply. He treated it heavily with chemical disinfectants, not aware of the associated health risks of drinking swim water, nor making the connection between those harsh chemicals and the failure of several water heaters.

A big issue is people who have no treatment and may have done fine without it for decades. It's often hard to convince them that they need water treatment, particularly since risks have increased with the population growth and influx of exotic vectors and diseases. Even without new threats, these residents often don't understand that although they may have no ill effects from their water because they've developed immunities to its unique microflora and common contaminates, others not so immunized, such as a visiting grandmother, may suffer adverse effects. One sad incident occurred when short term/emergency foster children were placed into care in a home that had a catchment treatment system, but sadly the ultraviolet light in their system was no longer working. The foster family was not ill, having built up immunities to their water, but unfortunately the foster children, unused to the tank's bacterial biota, became ill. Inspectors who may have noted that there was an adequate treatment system at the house likely had no means or awareness to make water testing part of the placement process.

4.5 RAINWATER CATCHMENT PROGRAM BEGINNING

By 1999, the population had grown substantially in the rural neighborhoods. Complaints from residents getting ill from their water were getting more public attention. Only two studies on illness related to the use of water catchment had been done on the island. One study in 1993 linked the probability of getting *Leptospirosis* (a bacterial disease passed through contact with mammal urine) with catchment use (Sasaki *et al*., 1993). The other study was less formal and happened in the 1990's when national attention was drawn to people on catchment developing lead poisoning. Lead paint was sometimes used in older plantation homes to coat roofs and some used lead-headed nails to secure metal roofs. Some residents even lined the inside of their wooden tanks with lead paint to keep algae growth down. Without any oversight or knowledge, homeowners had little information to learn of the danger in which they had put their families.

Catchment tank vendors were the ones most people turned to for information on how to build and maintain a water system that didn't risk the health of the water user. Local businesses were primarily geared to selling and setting up tanks, pumps and water conveyance systems, not in toxicology or microbiology. Nevertheless, many vendors were very conscientious about providing good systems for their clients. Even with conscientious island vendors, there was little information available especially information relevant to island catchment needs. Mainland suppliers were not always aware of the unique issues. For example, treatment systems which were designed to improve pre-treated municipal water were sometimes sold for the raw (untreated) water of catchment users and obviously not up to the task.

In 1999, research on how to assist homeowners understand the threat of *Leptospirosis* was begun by the author, who worked in the University of

Hawaii's Cooperative Education program, leading to the start of a statewide rainwater catchment program (RCP).

A community survey was initiated to see if catchment users understood what *Leptospirosis* was, where it came from and if they thought they were at risk. It also asked general questions about the ownier's systems and maintenance. Responses pointed to a glaring lack of basic knowledge about how *Leptospirosis* was contracted, water quality in general, water-system maintenance and water treatment. The survey responses also demonstrated that there was a glaring lack of information available to the homeowners so they could learn more. Stunningly, not one person surveyed identified *Leptospirosis* as a contact hazard and not just an ingestion hazard.

To compound the lack of information available, there was only one laboratory at this time where people could get their water tested. That lab was 2–3 hour drive away for the majority of residents, a 4–6 hour round trip. Shortly thereafter that lab closed leaving no island options for individual water testing. State Department of Health labs do not perform tests for private water systems.

4.6 THE RAINWATER CATCHMENT PROGRAM

An important goal of the rainwater catchment program (RCP) was to enable residents to help themselves. To do this it needed to provide residents with good, comprehensive information. The RCP started with the production of informative guidelines for residents. The guidelines (Macomber, 2010) gave answers to essential catchment system questions, and the maintenance of those systems from raindrop to faucet. Funding from an NGO and the State Department of Health helped publish the guidelines so that they could be distributed without cost to state residents. The result was the nation's first statewide rainwater catchment system guidance. Over 40,000 have been distributed in hard copy form and continue to be available digitally.

As residents had no way of knowing if their water systems were contaminated or not, or if their water treatments worked, the second priority of the new RCP was enabling residents to monitor their own water quality. Simple, inexpensive test kits for fecal indicators (Figure 4.9, (Source: Authors)) were designed by the RCP using the Manja method (Manja *et al.*, 1982). These kits were then distributed or sold at cost through the University Extension office and later by local vendors who volunteered to assist in their distribution.

Initially testing was done at the University's Cooperative Extension office (Figure 4.10; Source: Authors), but as soon as a home test kit could be provided rural residents could easily pick up tests kits when they were in town and have them available when needed. This enabled the catchment owner to finally be able to manage their own systems, and know if what they were doing was successful. It also freed up the single RCP personnel to continue with other catchment

Figure 4.9 Home test kit.

Figure 4.10 RCP water tests.

outreach work since the popularity of the testing was immediately quite overwhelming and time consuming.

The Manja method was chosen because it used hydrogen-sulfide producing gut bacteria as indicators rather than the typical tests for *E. coli*. There are indigenous, non-gut *E. coli* found in the Islands which could lead to false positive results if using typical *E. coli* indicators (Hardina and Fujioka, 1991). Also, the Manja formula was less sensitive to temperature variations and could be used without incubation in lower elevations where temperatures were warm. This meant that a catchment user could do this test themselves at home (Rijal and Fujioka, 1995). One other note in favor of the Manja method testing is that the test results, if positive, encourages action by the homeowner due to its foul odor and color change from clear yellow to opaque black. This putrid ugly result has been known to convince even the adamant denier into cleaning his system. Once the program became established, the community need for it was easily confirmed and funding to expand services was easier to obtain.

4.7 RAINWATER CATCHMENT PROGRAM EXPANSION

4.7.1 Education

Education was always a key goal of the catchment program. Besides the guidelines, frequent community workshops explaining the 'problems and resolutions' for safe catchment use were offered throughout the island. Eventually, specialized workshops were offered (Figure 4.11). Topics included how to repair and troubleshoot pumps, how an ultraviolet light system works and other directly relevant subjects. Many simple handouts (Figure 4.12) were also created to simplify some topics, meet some specific needs and reach out in other languages for those with limited English. Seminars were provided to realtors, home inspectors, business owners, government agencies, businesses and other

Figure 4.11 Pipe fitter Rick Bishop explaining pump repair.

Figure 4.12 RCP Brochure examples. (*Source*: Authors).

specialized groups that needed to know more about catchment systems. Manned informational booths were set up in county fairs, community fairs, health fairs, and sustainability fairs. Local radio stations invited RCP to speak. Training was delivered for outreach workers in health fields, particularly those dealing in public health.

4.7.2 Available agent

One challenge worth mentioning is the fact that systems were quite individualized. Homes and businesses ranged from shacks to castles and water tanks and systems were just as diverse. There were few standards and the population consisted of many very self-reliant and creative problem solvers. There was rarely a once-size-fits-all answer to homeowner's questions. Even with comprehensive guidelines and seminars, having a person available to answer individual questions rapidly became an essential component of this valued pubic service, requiring more office hours and a message system.

4.8 COLLABORATIONS

4.8.1 Vendor support

Including and involving local vendors in the RCP was beneficial to all concerned. Vendors were often the first contact for new catchment owners or those with problems. Vendors benefited from free University literature to hand out, and inexpensive test kits to sell, increasing their public image and providing a service for their clientele. For the RCP, to have distribution of educational materials to a

Figure 4.13 Tradeshows were great outreach tools. (*Source*: Authors).

targeted audience helped spread awareness of water quality maintenance and risks. The RCP provided vendors and catchment users a place to call for questions and for more-sophisticated water testing.

Many vendors agreed to participate at community trade shows (Figure 4.13) promulgated by the RCP to service the catchment clientele. This allowed rural residents to make one trip for comprehensive information on various options available to them. It allowed vendors to show off their wares and services to potential customers. Finally, it allowed the RCP to display educational models and distribute materials to a targeted audience.

Working hand-in-hand with vendors was a great advantage to the RCP, the vendors and the catchment community. The RCP made it clear that it would not favor or promote any particular vendor over another, but tried to encourage the homeowner to discuss options and technologies with all of them. An interesting development of this partnership was that as emphasis on water quality was raised by the RCP, the sales of treatment systems began to outsell the water storage tanks, the previous focus of the catchment stores. This was a boom for the vendors which encouraged further collaboration, benefitting all involved.

4.8.2 Expanding research and collaborations

Scientific studies were important in determining and responding to program direction and consumer needs. Collaboration with experts in other fields helped bring in research grants. Collaborative programs were initiated in other US protectorates and territories where similar water quality/quantity problems exist.

For example, Train-the-Trainer workshops, conferences and specific programs such as introducing low-tech water quality improvement options, were run in various states in four Micronesian countries.

4.9 ENVIRONMENTAL CHANGE EFFECTS ON RAINWATER CATCHMENT

Understanding environmental changes and how they affect catchment systems is another area that needs more research and collaborations.

4.9.1 Weather/rainfall

Weather changes have brought challenges to residents. Droughts might be hard to imagine for a tropical island, however due to wind patterns, the topography of the Big Island includes deserts where rainfall is limited or intermittent. Residents in these areas often have larger catchment surfaces and tanks to get through the dry periods, however prolonged dry spells can still mean low water supplies. Where rainwater is usually plentiful, unexpected droughts can be a major problem because water storage and catchment surfaces are much too small. In addition, residents used to abundant supplies are not used to checking water levels in tanks and may be surprised by a 'drought'. It is common even after two weeks without rain on the rainy side of the island to hear a steady stream of water tanker trucks passing by to fill small tanks that have already run out of water. After three weeks without rain, the waiting time to get a truck available to deliver water gets long. A month long 'drought' is an emergency. Another instance of surprise is when there is fairly constant, but very light rain. This situation can lull residents into thinking there is plenty of water if tanks are not checked. Another unfortunate side effect of an empty tank is that 'on-demand' pumps get damaged when the water levels drop below the intake pipe. Climate change appears to have increased the variability of rainfall, making rain consistency less reliable.

All these issues can be addressed with increased conservation or greater storage and/or catchment surface, if one can afford it. But it is also important that residents adopt behavior patterns that make them aware of the weather, rainfall quantities, tank water levels and the need to conserve when necessary.

The county has helped considerably to make potable water available by getting a grant to install public water spigots (Figure 4.14) where rural residents could fill containers up to 50 gallons/day. There are currently 18 public spigot locations available on Hawai'i Island that supply residents with free water during droughts and year-round potable water. The spigots have been well used and much appreciated, the only downside being that they can only be installed where municipal water is available, which sometimes that means residents still may need to travel many miles to get water.

Figure 4.14 Resident getting water at County spigot. (*Source*: Authors).

Figure 4.15 Semi slug. (Photo coutesy of K. Howe).

4.9.2 Environmental change: Invasive species

Some environmental changes that the rainwater catchment program works to address are caused by invasive species. A recent example of a threat to water catchment users is the invasion and subsequent overpopulation of the semi-slug, *Parmarion martensi* (Jarvi *et al.*, 2018) (Figure 4.15). The semi-slug is an invasive species to Hawai'i that is an extremely efficient carrier of a parasitic worm *Angiostrongylus Cantonensis* which causes a disease known as Rat Lungworm. One of the characteristics of the semi-slug is that it likes to climb (Hollingsworth *et al.*, 2007), particularly towards moist places. Observations of semi-slugs climbing up and into water tanks are common. With the soft covers on the majority of the tanks on the island, there are often gaps where pipes go under the cover that make a perfect thoroughfare for the slug to get access to the tank. The semi-slugs often line the sides of the tank then drown as water levels rise with the rain, as they fall or get washed in. The microscopic parasitic worm escapes the drowned semi-slug and has survived 21 days in fresh water at the University of Hawai'i at Hilo School of Pharmacy's research lab (Howe *et al.*, 2019). Infections of the *A. cantonensis* can cause moderate to severe brain damage to those who ingest the parasites, the damage relative to the quantity of parasitic worms entering the body (Jarvi *et al.*, 2018). Since the infectious worms have been observed migrating to the bottom of the water column (Howe *et al.*, 2019) where the water intake valves are normally located, it is assumed that the chance of getting a high dose of parasites from an infested tank is possible. New studies from the University of Hawai'i Hilo School of Pharmacy show that treatment systems previously thought sufficient may not be adequate for blocking this new waterborne threat (Howe *et al.*, 2019).

Unfortunately the spread of the semi-slug isn't limited to the tropics. Climate change is spreading rat lungworm to other US locations where they have not been a problem before. For example, reports from Texas suggest

Figure 4.16 Puu Oo vent. (Photo courtesy of Hawaii Aerial Visions LLC).

that the semi-slug may be responsible for three cases of rat lungworm where people came into contact with parasite infested flood waters (Foster *et al.*, 2016; Hammoud *et al.*, 2017).

4.9.3 Environmental change: Volcanic

One unique environmental concern for catchment users in Hawai'i has been volcanic emissions (Figure 4.16). Hawai'i has had one fairly continuous volcanic eruption from 1983 through 2018 and numerous others. Even without an active outbreak of lava, there are still fumes, primarily sulfur, being emitted through fissures. Sulfur emissions create particularly acidic rain, which is one of the problems for catchment users. The more acidic the water, the more leaching there could be of all the collection, storage and distribution components. Another problem with volcanic eruptions is explosive events that put large amounts of particulate matter into the air, causing wide dispersal of heavy loads of contaminants.

Each eruption produces a different composition of gases and particulate matter that varies greatly in quantity, causing equally varied problems and solutions. While air, dust, rain, fumes, ash and particulates can be measured during an eruption, and assumptions can be made on its effects and toxicity, there had been no studies on the cumulative effect on catchment water quality over a period of time. This concerned the RCP office and triggered a study.

4.9.4 Environmental study

In 2009, an eruption produced an exceptionally large amount of emissions. A collaborative study among the Center for the Study of Active Volcanos, the County of Hawai'i, and the RCP was undertaken because of concerns over water quality in catchment tanks. There was concern that these emissions, which

included sulfur dioxide and sulfur trioxide being discharged at 700–1100 metric tons per day, would affect the acidity of collected rainwater. Hydrofluoric acid and hydrochloric acids were also present in the plume and both can form aerosols that will deposit on roofs and wash into the water supply. This caused concerns that levels of fluoride would exceed EPA maximum contaminate levels (Thomas & Macomber, 2010).

The team collected samples from 439 catchment tanks in 3 communities giving the residents immediate feedback on their pH levels and neutralization methods. In two communities downwind of these acidic fumes, the median pH of untreated catchment tank waters was 4.3–4.4. Lower extremes were 2.9–3.3. (Thomas & Macomber, 2010). Because of the RCP, the public was continuously informed by e-mail (or letter) of their individual water test results along with interpretations and suggestions for remediation action if needed. They were also given their overall community results, and comparative results (and conclusions) of all communities involved were shared with everyone. This type of feedback gave the participant a reward for their efforts and some ownership due to their participation. It paved the way for obtaining future contributions. Information was also supplied to community centers (and government officials) where it could be shared with non-participant residents to the benefit of the overall health of the community.

While collecting samples, data was also collected to obtain an overview of water availability, tank size, treatment techniques and systems, effects of wind on particulate distribution, and, surprisingly, attitudes of people with regards to water. For example, those living where rainwater was most abundant were much more lackadaisical in their water quality oversight. Those living in drier areas were much more vigilant and active in caring for their water supply. This information is very useful in directing the future of rainwater catchment programs.

4.10 SUMMARY

Harvesting rainwater is an ancient practice that can be adapted successfully to modern lifestyles. From the early days of plantations and redwood tanks, Big Island rainwater catchment usage has become an essential part of the lifestyle. Homes, subdivisions and towns steadily increase in size and often with that growth, comes a greater dependence on rain. Larger populations living closer together, introduced vectors, and invasive species mean challenging new threats to captured water quality. In spite of water quality challenges harvesting rain has proven to be a viable and sustainable water source.

Technological advances have offered more options for water treatment, but before treatment can be effective, one must understand the uniqueness of the local rainwater resource, the catchment system characteristics and the specific problems, and therefore the specific solutions needed to supply healthy water in sufficient quantities. The overall goal of the Hawai‘i RCP has been to increase

education, services, knowledge and awareness of water quality and quantity to enable residents to be competent stewards of their own water systems. Comparative surveys show a significant increase in residents using better systems and sufficient water treatment compared with before the RCP. Vendors have verified the changes in the community, noting revenue from treatment systems has grown and now exceeds that from water tank sales. These and other benchmarks are some of the verifications of a successful program.

In spite of continued challenges, such as climate change and volcanic emissions, rainwater catchment on the Big Island of Hawai'i will remain a major source of potable and non-potable water for large segments of the population for the foreseeable future. Although private water systems are not governed by the US Environmental Protection Agency, consumption of rainwater by large portions of the population is nevertheless a public health issue that should be fully addressed by the state and particularly county government. Without a dedicated champion or team and sustained funding, programs such as the Rainwater Catchment Program described here will soon fail to deliver the needed guidance and public health will suffer.

REFERENCES

Foster C. E., Nicholson E. G., Chun A. C., Gharfeh M., Anvari S., Seeborg F. O., Lopez M. A., Campbell J. R., Marquez L., Starke J. R. and Palazzi D. L. (2016). *Angiostrongylus cantoneensis* infection: a cause of fever of unknown origin in pediatric patients. *Clinical Infectious Diseases*, **63**, 1475–1478, https://doi.org/10.1093/cid/ciw606 (Accessed: May 2019).

Frazier A. G., Giambelluca T. W., Diaz H. F. and Needham H. L. (2016). Comparison of geostatistical approaches to spatially interpolate month-year rainfall for the Hawaiian Islands. *International Journal of Climatology*, **36**, 1459–1470, doi: 10.1002/joc.4437 http://rainfall.geography.hawaii.edu/howtocite.html (Accessed April 2019).

Hammoud R. A., Nayes S. L., Murphy J. R., Heresi G. P., Butler I. J. and Perez N. (2017). *Angiostrongylus cantonensis* Meningitis and myelitis, Texas USA. *Emerging Infectious Diseases*, **23**(6), 1037–1038. https://doi.org/10.3201/eid2306.161683.

Hardina C. M. and Fujioka R. S. (1991). Soil: The Environmental Source of *Escherichia coli* and *Enterococci* in Hawaii's Streams. *Environmental Toxicology and Water Quality* **6**, 185–195.

HFD. (2008). County of Hawaii Fire Department via The Hawaii Tribune Herald. Hilo, Hawaii. Redrawn digitally by author.

Hollingsworth R. G., Kaneta R. K., Sullivan J. J., Bishop H. S., Qvarnstrom Y., DaSilva A. J. and Robinson D. G. (2007). Distribution of *parmarion cf. martensi*, A New Semi-Slug Pest on Hawai'i Island, and its Potential as a Vector for Human *Angiostrongyliasis*. *Pacific Science*, **61**, 157–168.

HOVE. (2019). Hawaiian Ocean View Estates, https://hoveroad.com/community-links (Accessed: April 2019).

Howe K., Kaluna L., Lozano A., Torres Fischer B., Tagami Y., McHugh R. and Jarvi S. (2019). Water transmission potential of *Angiostrongylus cantonenesis*: Larval

viability and effectiveness of rainwater catchment sediment filters. *PLoS One* **14**(4), e0209813, https://doi.org/10.1371/journal.pone.0209813

HVNP. (2019). Hawaii Volcanos National Park, https://irma.nps.gov/Stats/SSRSReports/Park%20Specific%20Reports/Monthly%20Public%20Use?Park=HAVO (Accessed: April 2019).

Jarvi S. I., Howe K. and Macomber P. (2018). Angiostrongyliasis or rat lungworm disease: a perspective from Hawai'i. Current Tropical Medicine Reports Tropical Parasitology (A Sanchez, Section Editor). Springer International Publishing AG, part of Springer Nature. Published online: 05 February 2018 https://doi.org/10.1007/s40475-018-0132-z

KMC. (2007). Kilauea Military Camp, https://kilaueamilitarycamp.com/ (Accessed: April 2019). Personal communication and site tour by KMC water maintenance personnel.

KMC. (2019). Kilauea Military Camp, Recreational facilities, https://kilaueamilitarycamp.com/ (Accessed: April 2019).

Macomber P. (2010). Guidelines on Rainwater Catchment Systems for Hawaii. Mānoa: Collage of Tropical Agriculture and human Resources, University of Hawai.

Manja K. S., Maurya M. S. and Rao K. M. (1982). A simple field test for detection of faecal pollution in drinking water. *Bulletin of World Health Organization*, **60**(5), 797–801.

Rijal G. and Fujioka R. S. (1995). A Homeowners Test for Bacteria in Cistern Waters, Water Resources Research Center. University of Hawaii at Manoa, Honolulu, Hawaii.

Sasaki D. M., Pang L., Minette H. P., Wakida C. K., Fujimoto W. J., Manea S. J., Kunioka R. and Middleton C. R. (1993). Active surveillance and risk factors for *Leptospirosis* in Hawaii. *American Journal of Tropical Medicine Hygiene*, **48**, 35–43.

Thomas D. M. and Macomber P. S. (2010). Impact of Persistent Degassing of Kilauea Volcano on Domestic Water Supplies. American Geophysical Union. Presented 13-17 December 2010 American Geophysical Union, Fall meeting, San Francisco, CA USA. Also presented 14-17 September 2009, American Rainwater Catchment Systems Association Conference, Decatur GA USA.

U.S. Census Bureau. (Data released on December 19, 2018) http://dbedt.hawaii.gov/economic/datawarehouse/ (Accessed: April 2019).