Confirming the Natural Presence of Fecal Indicator Bacteria in Environmental Soil and Water on the Islands of Kauai and Hawaii

Problem and Research Objectives

Our laboratory at the Water Resources Research Center, University of Hawaii, has been conducting water quality studies in the state of Hawaii for the past 30 years. One of the most significant results of these studies is our conclusion that U.S. Environmental Protection Agency (EPA) hygienic recreational water quality standards are not applicable to the state of Hawaii (R.S. Fujioka et al., 1988, *Toxicity Assessment* 3:613–630; R.S. Fujioka and M.N. Byappanahalli, 1996, WRRC-96-01, Proj. Compl. Rep., 50 pp.). This conclusion is based on years of monitoring data which show that all streams on the island of Oahu consistently exceed the EPA hygienic recreational water quality standards based on concentrations of fecal indicator bacteria (i.e., fecal coliform, *Escherichia coli*, and enterococci) (R.S. Fujioka et al., 1988, *Toxicity Assessment* 3:613–630; C.M. Hardina and R.S. Fujioka, 1991, *Environ. Toxicol. Water Qual.* 6:185–195). This conclusion is also based on our assessment that the two assumptions used by EPA to interpret the public health risks of recreational water quality standards are not applicable to Hawaii. The reason is because environmental conditions in Hawaii differ from environmental conditions in temperate regions of the world where monitoring data were obtained for use in establishing recreational water quality standards.

The first assumption used by EPA is that there are no significant environmental sources of fecal indicator bacteria. Thus, EPA assumes that the source of fecal indicator bacteria in natural environmental waters is sewage or animal feces. Moreover, when the numbers of these fecal indicator bacteria exceed their respective maximum contaminant levels, under EPA guidelines these waters are considered polluted with sewage and the sewage-borne pathogens will pose an unacceptable risk to users of those waters. However, based on our studies, we have determined that soil in Hawaii is a natural habitat for fecal indicator bacteria. Moreover, rain, which is the source of water for all streams, will transport these soil-bound fecal indicator bacteria to all streams (C.M. Hardina and R.S. Fujioka, 1991, *Environ. Toxicol. Water Qual.* 6:185–195). Thus, soil rather than sewage or feces of animals is the major source of fecal indicator bacteria recovered from all streams of Oahu.

The second assumption used by EPA is that fecal indicator bacteria cannot multiply under natural environmental conditions. However, the results of our studies have shown that environmental conditions (temperature, moisture, nutrients) in Hawaii's soil environment allow these bacteria to multiply (R.S. Fujioka and M.N. Byappanahalli, 1998, WRRC-98-04, Proj. Compl. Rep., 85 pp.; M.N. Byappanahalli and R.S. Fujioka, 1998, *Water Sci. Tech.* 38:171–174). This second assumption is of critical importance because many significant sewage-borne pathogens such as human enteric viruses and protozoa (*Giardia*, *Cryptosporidium*) are not able to multiply under environmental conditions. As a result, if fecal indicator bacteria multiply in the environment, their numbers no longer represent the degree of sewage or fecal contamination and no longer represent the same risk for water-borne transmission of sewage-borne pathogens.

Since the two assumptions used by EPA to establish and interpret hygienic water quality standards are not applicable to Hawaii, we concluded that the recreational water quality standards also are not applicable to Hawaii. An important consequence of applying the EPA recreational water quality standards to Hawaii is that all streams will consistently exceed the hygienic water quality standards. Although we have obtained data to show that the source of these fecal indicator bacteria in streams is primarily from a non-sewage source (soil), current monitoring data are not useful because they cannot be used to determine when streams are really contaminated with sewage. To address this need, we have shown that other alternative fecal indicators (*Clostridium perfringens*, FRNA coliphages) can be used to determine when streams are contaminated with sewage because they cannot multiply under environmental conditions and they are consistently present in high concentrations in sewage (R.S. Fujioka and L.K. Shizumura, 1985, *J. Water Poll. Contr. Fed.* 57:986–992; R.S. Fujioka et al., 1997, *Proc. Water Environ. Fed. 70th Ann. Conf. and Expo.*, 405–411; K. Luther and R. Fujioka, 2002, *WEFTEC 2002 Conf. Proc.*, 75th Ann. Tech. Exhib. and Conf., 12 pp. on CD-ROM).

The identified problem is the potential limitation of our studies because most of the data were collected for the island of Oahu and the results are assumed to be similar for all of the other islands of the state of Hawaii. However, it is well known that the soil composition and geology of the various islands of Hawaii differ because the age of the islands differs. In this regard, the islands arose from the eruption of lava from a single hot spot on the ocean floor. Over time, this hot spot moved eastward, leaving a chain of eight islands. Kauai is the oldest island at 4 to 5 millions years old, and Oahu is the second oldest at 2 to 3 million years old. Molokai, Maui, Lanai, and Kahoolawe, the middle islands, follow in age at about a million years old. Hawaii, the youngest island, is reported to be only 0.7 million years old.

The overall goal of this study is to determine whether environmental monitoring data for fecal coliform, *E. coli*, enterococci, *C. perfringens*, and FRNA coliphages, which have been used to assess the hygienic quality of recreational waters for the island of Oahu, are equally applicable to all of the other islands of the state. The objective of Phase I of this study was to determine whether monitoring data obtained from soil and recreational water samples from the island of Oahu are similar to those obtained from similar types of environmental samples from the island of Kauai, which represents the oldest island. The objective of Phase II was to determine whether monitoring data obtained from soil and recreational water samples taken from the island of Oahu are similar to those obtained from similar types of samples taken from the island of Hawaii, which represents the youngest island. It should be noted that Phase II of this study was not funded, and therefore this report is restricted to Phase I or to assessing the quality of water on the island of Kauai. A no-cost extension was granted for the Phase I work.

Methodology

EPA-approved methods (Standard Methods) to assay for fecal coliform, *E. coli,* and enterococci were used to assay the soil and stream water samples obtained from Kauai. These same water samples were also assayed for *C. perfringens* (J.W. Bisson and V.J. Cabelli, 1979, *Appl. Environ. Microbiol.* 37:55–66) and for FRNA coliphages (J. Debartolomeis and V.J. Cabelli, 1991, *J. Appl. Environ. Microbiol.* 57:1301–1305) using methods developed by EPA. During this study, we traveled to Kauai on several occasions to meet with agency personnel and to obtain soil and water samples. Arrangements were made to have water samples sent to us from Kauai on approximately a monthly basis. The Hanalei watershed and the Nawiliwili watershed were the primary study sites.

Principal Findings and Significance

Kauai differs from Oahu in three significant ways. First, it is an older island. Second, there is greater rainfall there, resulting in more and larger streams. Third, Kauai still relies on cesspools to collect and treat wastewater (this method of wastewater collection and treatment is not used throughout most of Oahu). Cesspools are not satisfactory systems, and some of the inadequately treated wastes from cesspools are expected to contaminate the nearby streams and coastal waters. This study focused on the Hanalei and Nawiliwili watersheds. In this regard, we worked closely with the Clean Water Branch of the state of Hawaii and with environmental organizations on Kauai that are responsible for assessing the water quality at these two watersheds. For the Hanalei watershed, we worked closely with and made presentations to members of the Hanalei Heritage River Program. For the Nawiliwili watershed, we worked closely with and made presentations to the Nawiliwili Bay Watershed Council.

The principal findings and significance of this study are as follows. First, as also observed on Oahu, soil samples from Kauai contained high concentrations of fecal indicator bacteria such as fecal coliform, *E. coli*, and enterococci. The significance of this observation is the identification of the same environmental source of fecal indicator bacteria on both Oahu and Kauai. Second, as also observed on Oahu, the streams on Kauai consistently contained fecal coliform, *E. coli*, and enterococci at concentrations that exceeded hygienic water quality standards. The significance of this observation is the impact of the environmental source (soil) of fecal indicator bacteria, which explains the consistently high concentrations of fecal indicator bacteria in the streams on Kauai. Third, as also observed on Oahu, the concentrations of *C. perfringens* in Kauai streams were low but increased when sewage spill was observed. The significance of this observation is the applicability of monitoring for *C. perfringens* as a reliable means of determining when recreational waters are contaminated with sewage. Fourth, as also observed on Oahu, marine coastal water sites that receive land-based discharges (streams, storm drains) contained elevated levels of fecal indicator bacteria. The significance of this observation is the predictable way in which land-based or nonpoint sources of pollution can be expected to increase fecal bacterial contamination at coastal water sites. Fifth, unlike Oahu, many of the streams on Kauai contained elevated levels of FRNA coliphages. The major significance of this observation is that FRNA coliphages may be the best indicator for the contamination of stream water by cesspools. This conclusion is based on the small size and stability of FRNA coliphages, characteristics which enable them to be readily transported through soil to contaminate nearby streams. In summary, the monitoring data for Kauai provided similar results as the monitoring data for Oahu. These results indicate that the conclusions on water quality for Oahu are applicable to Kauai.