ADDRESSING THE NEEDS OF THE WATER AGENCIES IN HAWAII, GUAM, PUERTO RICO, AND SOUTH FLORIDA

PURPOSE FOR ADDENDUM

Chapters 1 through 4 of this report represent the proceedings of the Tropical Indicator Water Quality Workshop. However, during the review of the draft report by the experts, many issues not specifically discussed by the experts at the workshop were raised. Two of these issues were determined to be important by the authors of this report (Roger Fujioka and Muruleedhara Byappanahalli) and thus are addressed in this addendum. The first issue was related to the question of how to gage the success of this workshop as well as to one of the workshop recommendations of meeting the needs of a regulator for effective decision-making. In this regard, an unstated but expected objective of this final report was to provide the water agencies responsible for recreational waters in Hawaii, Guam, Puerto Rico, and south Florida with a document to understand the findings of this workshop and then to develop best management practices with EPA. However, it was recognized that of the four water agencies, only the Hawaii water agency (Department of Health, State of Hawaii) has a long history of communicating this problem with EPA and was the only agency that participated in the planning and implementation of this workshop. As a result, this water agency is well prepared to receive and understand the findings of this workshop report. The three other water agencies do not have a long history of communicating this water quality problem with EPA and may not have water microbiologists on their staff to adequately explain the discussions and findings in this report. Moreover, these three agencies were not involved in the planning or implementation of this workshop and are not primed to receive this workshop report. It was thus concluded that personnel in the water agencies of Guam, Puerto Rico, and south Florida may not be adequately prepared to fully understand the consensus statements of this workshop based only on the contents of Chapters 1 through 4. It was concluded that the needs of the four water agencies could be best served by writing a section of this report to specifically address their needs as well as the needs of others who will read this report with insufficient background in water quality microbiology.

The two issues covered in this addendum are as follows: (1) to clarify the significance of the findings of this workshop as they pertain directly to these water agencies and also to provide each water agency with some recommendations and (2) to inform the personnel of water agencies and other readers of this report that recent publications provide additional and relevant information on questions raised during the workshop.

ISSUE ONE
SIGNIFICANCE OF WORKSHOP CONSENSUS STATEMENTS TO WATER AGENCIES IN HAWAII, GUAM, PUERTO RICO, AND SOUTH FLORIDA

Explanation of the Consensus Statements and Needs of the Water Agencies

Consensus statement one

> Soil, sediments, water, and plants may be significant indigenous sources of indicator bacteria in tropical waters.

In this consensus statement, the experts concluded that soil, sediments, water, and plants may be significant indigenous sources of indicator bacteria in tropical waters. This conclusion was based on data presented by scientists from Hawaii, Guam, Puerto Rico, and south Florida that fecal indicator bacteria can be consistently recovered from various environments (soil, sediments, water, plants). Thus, this consensus statement addressed the problem of significant indigenous sources of fecal indicator bacteria in tropical waters, a factor which can reduce the reliability of current recreational water quality standards in these tropical locales. The basis for this problem is that the recreational water quality guidelines recommended by EPA assume that there are no significant indigenous sources of fecal indicator bacteria. Since evidence was presented that this assumption is not valid for conditions in Hawaii, Guam, Puerto Rico, and south Florida, the interpretation of the current recreational water quality standards may not be reliable at these sites.

The need identified by consensus statement one is to determine the extent to which significant indigenous sources of indicator bacteria occur in tropical waters within these four locations and whether this same observation is relevant for other tropical locations because similar environmental conditions of warm temperature, high humidity, and available nutrients can be expected at other tropical sites. However, the experts pointed out that there is insufficient evidence to determine the extent of water quality problems at other tropical locations. Moreover, it was pointed out that environmental conditions and sources of fecal indicator bacteria differed in the four tropical locations. For example, soil was identified as the environmental source of fecal indicator bacteria in Hawaii and Guam, and the same kinds of experiments were conducted at these two sites. However, in Puerto Rico, bromeliads in a pristine rain forest were identified as the environmental source of fecal bacteria whereas in south Florida, tidally influenced soil banks next to an inland freshwater river were identified as natural sources of fecal bacteria. Another identified need was to conduct similar experiments at the four tropical locations (Hawaii, Guam, Puerto Rico, south Florida) as well as other tropical sites so data on significant indigenous sources of fecal indicator bacteria can be better compared.

Consensus statement two

> The inherent environmental characteristics of the tropics affect the relationships between indicators of fecal contamination (*E. coli*, fecal coliforms, enterococci) and health effects observed in bathers, which may compromise the efficacy of EPA guidelines.

In this consensus statement, the experts concluded that tropical climates have inherent characteristics such as year-round warm temperature, high humidity, and available nutrients and that these chracteristics differ from environmental conditions in temperate climates. Environmental conditions in tropical climates are more supportive of prolonged survival and growth of fecal indicator bacteria. The problem identified by consensus statement two is that important differences in the environment can change the relationship between the sources and numbers of fecal indicator bacteria in recreational waters. As a result, the EPA guidelines, which were developed under temperate conditions to interpret recreational water quality standards, may not be applicable to some tropical environments. In this regard, three factors accentuate the differences in interpreting recreational water quality standards under temperate conditions and under tropical conditions. First, EPA only used data from temperate conditions to establish recreational water quality criteria, and these same criteria are applied to temperate and tropical climates. Second, one of the water quality guidelines used by EPA is its acceptance of the assumption that there are no significant environmental sources of fecal indicator bacteria. However, monitoring evidence was presented that this assumption does not apply to tropical areas where these bacteria have been documented to persist in the environment and to contribute to their elevated numbers in environmental waters. Third, in establishing the numbers of fecal indicator to assess acceptable risk levels for use of recreational waters, EPA obtained data from beaches contaminated with sewage and therefore the source of fecal indicator bacteria exposed to swimmers was assumed to be sewage. In contrast, the predominant sources of fecal indicator bacteria in recreational waters in Hawaii, Guam, Puerto Rico, and south Florida were determined to be from environmental sources rather than from sewage.

The identified need is to re-assess the assumptions and interpretations of the current recreational water quality standards as applied to tropical environments. Moreover, since the relationship between numbers of fecal indicator bacteria in environmental waters and human health effects is determined by the source of fecal indicator bacteria, an additional need is to develop test methods that can identify the sources of fecal indicator bacteria as originating from humans, animals, or the environment.

Consensus statement three

> Fecal indicator bacteria (fecal coliforms, *E. coli,* enterococci) can multiply and persist in soil, sediment, and water in some tropical/subtropical environments (Hawaii, Guam, Puerto Rico, south Florida).

In this consensus statement, the experts concluded that sufficient data have been presented to indicate that under conditions in some tropical/subtropical environments (Hawaii, Guam, Puerto Rico, south Florida) multiplication and persistence of fecal indicator

bacteria can occur in soil, sediment, plants, and water environments. Several lines of evidence supported this conclusion. First, monitoring data from four tropical locales show consistently high concentrations of fecal indicator bacteria from soil, plants, sediment and environmental sources of water, indicating that these fecal bacteria are persistently present in these environments. Second, results of many laboratory and some controlled field experiments provided evidence for multiplication of fecal indicator bacteria in soil, sediments, water, and plants. Third, the environmental conditions at these tropical and subtropical study sites were shown to be suitable for the growth of fecal bacteria. Fourth, the principles of microbial ecology—which address issues concerning the occurrence, distribution, survival, and growth of microorganisms in the environment—support the probability that fecal bacteria have the capacity to multiply under tropical environmental conditions.

The problem identified by this consensus statement is that fecal indicator bacteria that multiply in the environment are less reliable indicators of sewage contamination than fecal indicators that do not multiply in the environment. The basis of this problem is that many pathogens (human enteric viruses, *Giardia*, *Cryptosporidium*) cannot multiply in the environment. Moreover, in the development of recreational water quality criteria, EPA accepted the assumption that the fecal indicator bacteria will not multiply to any significant level under environmental conditions. Thus, if this assumption is not applicable to tropical environments, the application of the water quality standards in tropical environments will not be reliable.

The first need identified by consensus statement three is to re-assess the assumption used by EPA that fecal indicator bacteria will not multiply in ambient tropical environments. In this regard, the principles of microbial ecology should be incorporated into the development of water quality guidelines. Another need is to determine the extent to which fecal indicator bacteria can multiply in various environments (soil, sediment, water) in different tropical locations. Yet another need is to consider monitoring for alternative fecal indicators that will not multiply in tropical environments, to overcome the limitations of using the current fecal indicator bacteria that have been reported to multiply in tropical environments.

Consensus statement four: The preferred version

> Recreational water quality guidelines for the tropics/subtropics should be supplemented with additional alternative indicators (*C. perfringens*, coliphages) for watershed assessment (or sanitary survey).

Consensus statement four: The alternate version

> In the absence of a predominant point source pollution, recreational water quality guidelines for the tropics/subtropics should be supplemented with additional alternative indicators (*C. perfringens*, coliphages) for watershed assessment (or sanitary survey).

The experts crafted two consensus statements to address the problem of what to do when recreational water quality standards are not suitable for some tropical locations. The preferred version of consensus statement four was favored by more experts. The alternate version of consensus statement four was favored by some experts and found to be acceptable to most of the other experts. Both versions of the consensus statement identified two problems. The first problem is the unreliability of applying only the current recreational water quality standards to determine health risks to swimmers in four tropical locations (Hawaii, Guam, Puerto Rico, south Florida). The second problem recognizes the need to monitor tropical water using alternative fecal indicators such as coliphages and *C. perfringens*. These alternative indicators can provide additional and reliable information related to fecal contamination that cannot be obtained by monitoring for only indicators identified for current recreational water quality standards.

The need identified by the two versions of consensus statement four is to further explore the usefulness of monitoring tropical waters for coliphages or *C. perfringens* because these two alternative fecal indicators will not multiply under environmental conditions and their concentrations in tropical waters were reported to be reliable indicators of sewage contamination. However, developing specific guidelines on how these alternative fecal indicators can be used was not discussed. One possibility is to continue to use the current water quality standards and to monitor for these alternative fecal indicators using a supplemental or additional test to obtain additional data that can assist in determining when the source of contamination is sewage rather than environmental. This approach is applicable to sites that generally meet current recreational water quality standards but are periodically contaminated with environmental sources of fecal indicator bacteria. The second possibility is to use these alternative fecal indicators to establish an alternative or new water quality standard to be used in place of the current recreational water quality standards. This approach is applicable to sites where the quality of water routinely exceeds the current recreational water quality standards and evidence has been obtained that the primary source of these fecal indicators is environmental (e.g., soil) rather than sewage.

State of Preparedness and Recommendations for Water Agencies in Hawaii, Guam, Puerto Rico, and South Florida

Current status and recommendation for water agency in Hawaii

In Hawaii, there has been a long history of cooperative efforts among researchers at the University of Hawaii and personnel of the Hawaii Department of Health as well as the City and County of Honolulu to solve water quality problems in the state. This has resulted in a series of water quality studies by University of Hawaii researchers covering the period from the early 1970s to present. During this period, the following major findings were made. First, all streams on Oahu routinely exceed the recreational water quality standards and therefore it is not possible to determine when streams are contaminated with sewage when EPA-recommended standards are applied. Second, the primary source of the high concentrations of fecal indicator bacteria in streams was identified as environmental (soil) and did not reflect sewage contamination. In this regard, coastal waters that receive stream and storm drain runoff often exceeded the recreational water quality standards. Third, evidence was obtained

to show that fecal indicator bacteria (*E. coli*, fecal coliform, enterococci) are able to multiply in the soil environment of Hawaii. Fourth, monitoring streams and coastal waters for *C. perfringens* provided reliable data to determine when sewage contamination had occurred. Moreover, alternative recreational water quality standards were established for *C. perfringens* based on exceeding ambient levels and demonstrating presence of sewage in these waters. These standards have been used to make decisions on closing and opening beaches.

In an attempt to better manage the quality of environmental waters, the Hawaii Department of Health independently completed several monitoring programs to confirm the above four conclusions provided by University of Hawaii researchers. The problem facing the state is that years of monitoring data have shown that the current recreational water quality standards are routinely exceeded in most streams in Hawaii. As a result, state officials made a request to EPA to approve the use of the *C. perfringens* standards for Hawaii because these standards provided more reliable data for sewage contamination. EPA has not approved these proposed standards because they were not developed using the EPA guideline of establishing standards based on measurable health effects. Thus Hawaii must continue to monitor all recreational waters using EPA-recommended fecal indicator bacteria, even though the monitoring data obtained does not allow state officials to reliably determine when environmental waters are truly contaminated with sewage and pose a real health threat.

Upon receipt of this final report, Hawaii should re-evaluate its water quality problem and seek the advice of EPA. The first recommendation is it should consider changing its marine recreational water quality standard from the current state standard of 7 CFU enterococci/100 mL to the EPA-standard of 35 CFU enterococci/100 mL. The Hawaii standard appears to be the most restrictive standard used in all of the states and appears to be unreasonably restrictive for the state, especially since environmental sources of enterococci and *E. coli* have been identified. State officials should consult with EPA epidemiologists to determine whether the 7 CFU enterococci/100 mL standard is predictive of 10 diseases per 1,000 people, as published by EPA, and whether this restrictive standard should continue to be used in Hawaii. The second recommendation is Hawaii should seek EPA's assistance on the best way to resolve the water quality problems in the state and in particular on determining what standards can be reasonably applied to the freshwater streams because current standards are routinely exceeded. In this regard, two relevant but controversial conclusions were made at the workshop. The first conclusion was the decision not to evaluate the usefulness of Hawaii's proposed *C. perfringens* standards because the recommended numbers of this bacteria in recreational waters were not developed according to current EPA recommendations that water quality standards must be based on measurable health effects. The second conclusion was to encourage further studies to monitor streams for coliphages and *C. perfringens* as promising alternative fecal indicators. However, guidelines in the use of these alternative fecal indicators were not established. A major criterion that needs to be agreed upon is whether the use of these alternative fecal indicators will only be acceptable when their numbers in recreational waters can be associated with measurable health effects. This criterion will likely require that an epidemiological study be performed at recreational water sites where the concentrations of *C. perfringens* will predictably increase as a result of sewage discharge. Since these kinds of sites are not available in Hawaii, these kinds of experiments cannot be expected to be conducted here.

If EPA is charged with assisting water agencies in tropical locations to develop guidelines and possibly alternative or supplemental standards based on concentrations of coliphages or *C. perfringens*, a direct dialogue with local officials is recommended because the Department of Health has collected years of data that document the concentrations of *C. perfringens* at many of the recreational sites in the state. This is not the situation at the three other tropical sites considered in this workshop. The resolution of the problem in Hawaii can serve as a model for other tropical locations. Finally, the Hawaii water agency should seek the assistance from water agencies in Guam, Puerto Rico, and south Florida to gain a worldwide perspective on this problem.

Status and recommendations for water agency in Guam

Researchers at the University of Hawaii have previously worked with personnel at the University of Guam and the Guam water agency for water quality (Guam Environmental Protection Agency) to document the problem of elevated concentrations of fecal indicator bacteria in the streams and coastal waters of Guam. Since similar methods were used in Hawaii and in Guam, the results are comparable. The experiments in Guam resulted in two conclusions that were similar to those obtained in Hawaii. First, streams consistently contain high concentrations of fecal indicator bacteria (fecal coliform, enterococci, *E. coli*). Second, high concentrations of fecal indicator bacteria are present in the soil environment. Thus, in Guam as in Hawaii, the primary source of fecal indicator bacteria in streams is environmental (soil) rather than sewage, and monitoring for only the EPA-approved fecal indicators may not provide reliable data to determine when streams and storm drains are contaminated with sewage.

Although the water quality problems in Hawaii and Guam are similar, there are some basic differences. First, Guam is located closer to the equator than Hawaii and therefore has a higher mean temperature and higher humidity throughout the year. These conditions may be more suitable for the growth of fecal indicator bacteria in the environment. Second, bird feces are not sources of fecal indicator bacteria because the brown snake has essentially eliminated the bird population in Guam. Third, Guam has adopted the EPA-recommended recreational water quality standard rather than the more restrictive standard adopted by Hawaii. Fourth, Guam has not obtained extensive monitoring data on the use of *C. perfringens* or FRNA coliphages. Fifth, Guam has a greater prevalence of fringing reefs close to shore and shallow-water areas that extend a great distance from shore. This condition provides for longer residence time of land-based (streams, storm drain) contamination of coastal water because there is less dilution of freshwater by ocean water and because ocean currents do not rapidly transport land-based freshwater discharges out to sea. In this regard, fringing reefs create conditions that are more conducive for children to wade and play in coastal water areas, thus increasing the exposure time to any contaminants in these waters. Sixth, sewage disposal and transport away from coastal waters appear to be less effective in Guam than in Hawaii. Taken together, these conditions indicate that Guam should make it a priority to implement monitoring methods that will reliably determine when its recreational waters are contaminated with sewage.

Personnel at the Guam water agency are well aware of the similarities between the water quality problem in Hawaii and in Guam. However, during the past few years, the

Guam water agency has not taken an active role in addressing its water quality problem with EPA. One reason is that Guam does not have a resident research water quality microbiologist to conduct independent research on the water problem. Another reason may be related to waiting for Hawaii to resolve its problem with EPA. Upon receipt of the final report of this workshop, the Guam water agency should re-assess its water quality problem and consult with EPA for assistance. It should also consult with the water agencies in Hawaii, Puerto Rico, and south Florida to gain a worldwide perspective on this problem.

Status and recommendation for water agency in Puerto Rico

In Puerto Rico as in Hawaii, researchers at the local university (University of Puerto Rico) have conducted numerous studies over an extended period of time (from the 1970s to the present). These studies document that due to environmental sources of fecal indicator bacteria, the current recreational water quality standards are not useful. Coliphages were proposed as better fecal indicators than current fecal indicators, but water quality standards using coliphages have not been developed. For some reason, the water agency in Puerto Rico has not actively sought assistance from EPA to resolve the water quality problem identified by the University of Puerto Rico researchers. University scientists can identify problems within the state or territory, but they do not have the authority to represent the government's position because only government water agencies have the authority and responsibility to identify water problems within their state or territory and to seek assistance from EPA and other agencies. Upon receiving the final report of this workshop, the water agency in Puerto Rico should re-assess the problem of water quality in Puerto Rico. It should immediately consult with Dr. Gary Toranzos, the scientist responsible for generating most of the relevant data from Puerto Rico. The water agency should also consult with EPA to resolve the water quality problem in Puerto Rico. Finally, the water agency in Puerto Rico should establish communications with water agencies in Hawaii, Guam, and south Florida to gain a worldwide perspective of this problem.

Status and recommendation for water agency in south Florida

Recently, the same kinds of water quality problems as identified in tropical climates have been identified at a specific subtropical location of south Florida (Fort Lauderdale). The scientist directing this study is Dr. Helena Solo-Gabriele of the University of Miami. Although the site represents a small area in south Florida, extensive studies have been conducted to show that fecal indicator bacteria (fecal coliform, enterococci, *E. coli*) appear to be multiplying in soil located near a riverbank periodically immersed by tidally controlled river water. The study data indicate that the current recreational water quality standards are not reliable at this river site. At the time of this workshop, insufficient studies were completed in south Florida to identify alternative fecal indicators that could be used to provide more reliable data to assess sewage contamination.

The current status in south Florida is that data have been presented to show that multiplication of fecal indicator in the soil next to the river is occurring under ambient conditions and therefore the current recreational water quality standards are not useful to determine the hygienic quality of water at this site. Personnel from county and state water agencies in Florida, as well as representatives from EPA, are well aware of these studies. The problem in assessing this set of data may be related to whether the problem is restricted to

only this site or whether this water quality problem affects other areas in Florida. Upon receiving the final report of this workshop, the water agency for Florida should re-assess the problem of water quality in Florida. It should immediately contact Solo-Gabriele, since she is the scientist who has obtained most of the relevant data. It should initiate communications with EPA to seek assistance in solving this problem. It should contact the water agencies in Hawaii, Guam, and Puerto Rico to gain a worldwide perspective of this problem. An additional recommendation is for the state to initiate planning for some carefully designed studies to be expanded to other sites in Florida. In this regard, an ideal opportunity is presented to examine the impact of tropical and temperate climates on the fate of fecal indicator bacteria in the environment because Florida covers a transitional area in terms of subtropical to temperate climates. Thus, many of the questions regarding environmental effects (tropical versus temperate) can be addressed by conducting comparative experiments in south, central, and northern Florida, as environmental conditions change from subtropical to temperate.

Relevant report from Trinidad

Although the focus of this workshop was to address the problem at the four tropical locations (Hawaii, Guam, Puerto Rico, south Florida), Ms. Christine Bullock presented the results of an epidemiological and water quality study conducted in Trinidad, West Indies. This report was relevant because Trinidad is considered a tropical island and environmental conditions there should be similar to those in Hawaii, Guam, and Puerto Rico. The epidemiological study, which was similar in design to the EPA study, focused on comparing the quality of water at marine beaches contaminated with sewage as compared to marine beaches not contaminated with sewage. As previously discussed in Chapter Two, the results of this study were similar to the results of the EPA study. It showed that as the fecal indicator counts at beaches contaminated with sewage increased, incidences of gastroenteritis among swimmers also increased. These results show that even under tropical environments, when sewage contamination of marine waters occurs, the concentrations of fecal indicator bacteria are predictive for the transmission of gastroenteritis. This study did not examine any freshwater sites or land-based runoff; therefore, the effect of the tropical environment on the sources of indigenous fecal indicator bacteria was not addressed. The recommendation is that water agencies in Trinidad should conduct some experiments similar to those conducted in Hawaii, Guam, Puerto Rico, and south Florida to determine if indigenous sources of fecal indicator bacteria are present in land-based sources of soil, water, and plants in Trinidad.

ISSUE TWO
INCLUSION OF ADDITIONAL AND RELEVANT PUBLICATIONS

Examples of Recent Relevant Reports

During the more than two years since the end of the workshop in March of 2001, the findings of many additional and new publications were raised by the reviewers of this report. Some of these additional publications provide information that were not available at the workshop and address some of the questions raised at the workshop. Some examples of these additional publications are discussed below.

One of the conclusions of the workshop was that there is insufficient evidence to indicate that fecal bacteria can persist and possibly multiply on plants. In this regard, recent publications by Muller et al. (2001) and Ott et al. (2001) have reported that many enterococci can be recovered from forage grass in Germany. The conclusion of these papers and earlier papers (Ott et al., 1998; Ulrich and Muller, 1998) indicates that enterococci are part of the microflora of grasses. These recent papers from Germany support the earlier findings by Mundt et al. (1962) that fecal streptococci can be recovered from plants in Tennessee during the summer months but not during the winter months. These results indicate that summer months can provide suitable conditions for *E. coli* and enterococci to multiply even in temperate areas of the world.

Evidence that fecal indicator bacteria (*E. coli*, enterococci) can multiply in the environment was presented and accepted by many of the experts but not by all. Several additional publications support the conclusion that fecal indicator bacteria are able to multiply in the ambient environment. Gauthier and Archibald (2001) reported that many coliforms (*Klebsiella* spp., *E. coli*, *Enterobacter* spp., *Citrobacter* spp.) as well as enterococci are able to multiply in mill water from pulp and paper mills. In this regard, the results of an earlier publication that *Klebsiella pneumoniae* can grow in paper waste mill was one of the reasons for stating that fecal coliforms were not reliable indicators of fecal contamination. Recognition that environmental sources and environmental amplification of fecal indicator bacteria can occur is important when these sources provide elevated concentrations of fecal indicator bacteria in coastal waters, leading to beach closures. In this regard, a number of studies have been completed on the sources of fecal indicator bacteria in coastal waters where numerous beach closures have occurred. For example, at Huntington Beach, California, Grant et al. (2001) reported that enterococci may be multiplying in an inland marsh and could be the source of elevated enterococci contaminating that beach. Beach closure at Lake Michigan is another problem. A recent report by Whitman et al. (2003) indicated that multiplication of *E. coli* and enterococci on algae deposited on shorelines of Lake Michigan may be the reason for elevated concentrations of fecal indicator bacteria in this lake.

List of Some Recent and Relevant Publications

Ashbolt, N.J., M.R. Dorsch, P.T. Cox and B. Banens. 1997. Blooming *E. coli*, What do they mean? Chapter 10. In *Coliforms and E. coli: Problem or Solution?* ed. D. Kay and C. Fricker, 78–85. Cambridge, UK: The Royal Society of Chemisty.

Baele, M., L.A. Devriese, P. Butaye, and F. Haesebrouck. 2002. Composition of enterococcal and streptococcal flora from pigeon intestines. *J. Appl. Microbiol.* 92:348–351.

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Byappanahalli, M.N., M. Fowler, D.A. Shively, and R.L. Whitman. In press. Ubiquity and persistence of *Escherichia coli* within a midwestern coastal stream. *Appl. Environ. Microbiol.*

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Fujioka, R.S., and M.N. Byappanahalli. 2001. Microbial ecology controls the establishment of fecal bacteria in tropical soil environment. In *Advances in Water and Wastewater Treatment Technology*, ed. T. Matsuo, K. Hanaki, S. Takizawa and H. Satoh, 273–283. Amsterdam: Elsevier Science.

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Lipp, E.K., S.A. Farrah and J. Rose. 2000. Assessment and impact of microbial fecal pollution and human enteric pathogens in a coastal community. *Mar. Pollut. Bull*. 24:1–8.

Muller, T., A. Ulrich, E.M. Ott, and M. Muller. 2001. Identification of plant-associated enterococci. *J. Appl. Microbiol.* 91:268–278.

Mundt, J.O., J.H. Coggins and J.F. Johnson. 1962. Growth of *Streptococcus faecalis* var *liquefaciens* on plants. *Appl. Microbiol.* 10:552–555.

Ott, E.M., T. Muller, M. Muller, C.M.A.P. Franz, A. Ulrich, M. Gabel, and W. Seyfarth. 2001. *J. Appl. Microbiol.* 91:54–66.

Sjogren, R.E. 1995. Thirteen-year survival study of an environmental *Escherichia coli* in field mini-plots. *Water, Air, Soil Pollut.* 81:315–335.

Toranzos, G.A., and R.P. Marcos. 2000. Human enteric pathogens and soil-borne disease. Chapter 11 in *Soil Biochemistry*, vol. 10, ed. J.-M. Bollag and G. Stotzky, 461–481. New York: Marcel Dekker.

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Whitman, R.L, T.G. Horvath, M.L. Goodrich, M.B. Nevers, M.J. Wolcott, and S.K. Haack. 2002. Characterization of *E. coli* levels at 63rd Street Beach, City of Chicago. Project completion report submitted to City of Chicago, pp. 1–85.

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