PI-CASC Final Report

Project Title: Rainfall Driven Shifts in *Staphylococcus aureus* and Methicillin-Resistant *Staphylococcus aureus* (MRSA) in Hilo Bay, Hawai`i
Graduate Student(s): Louise Economy (UH Hilo, TCBES)
Faculty Advisor: Tracy Wiegner (UH Hilo, Marine Science)
Committee Members: Ayron Strauch (HI DLNR), Jon Awaya (UH Hilo, Biology)
Lead Institution: University of Hawai'i at Hilo

1. Summary of project goals. *Staphylococcus aureus* is a pathogen that is becoming increasingly prevalent in the environment, and intensifying risks of human infection. Recent evidence suggests that *S. aureus* has a watershed source, and this may be impacted by anticipated climatic changes, such as shifting rainfall and stream flow patterns. Therefore, climate change may affect loading of *S. aureus* to near-shore waters, and alter health threats to water users. To inform the community of health risks, and support land management policies to reduce these risks, this project investigated *S. aureus* and methicillin-resistant *S. aureus* (MRSA) within the Hilo Bay watershed. This watershed was an ideal location for this project, as it receives very high and variable rainfall and stream flow, and the bay is used for recreation, subsistence, and cultural practices (Fig. 1).

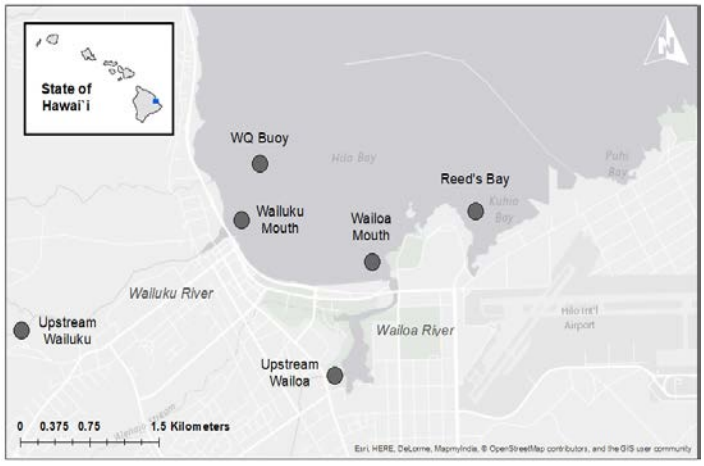


Figure 1. Stations in the Hilo Bay watershed in Hilo, Hawai'i, USA, that were sampled to examine climate-driven patterns in bacteria concentrations. Stations within the bay were selected to capture areas with variable impacts from rainfall, stream flow conditions, and groundwater inputs. Upstream stations were selected to confirm presence of bacteria within the watershed, and compare to coastal water conditions. Sample collection occurred on 20 days between March 2014 and March 2017.

The **first aim** of this project was to create a model to predict *S. aureus* and MRSA loading in Hilo Bay with anticipated climate changes in rainfall and stream flow. The model was created through the quantification of *S. aureus* and MRSA concentrations under variable rainfall conditions, and it may be used by managers to forecast the concentration of these pathogens in coastal waters. The **second aim** of this project was to determine which reservoirs in the watershed are sources of *S. aureus* and MRSA to near-shore waters. *S. aureus* and MRSA were quantified in potential sources, such as soils, sands, storm runoff, and wastewater. Water quality parameters, including nutrients, were also measured to gain insight into the sources of these pathogens within the watershed. The **third aim** of this project was to determine how the risk of MRSA infections is related to rainfall, the frequency of water use, specific water-based activities, and geographic location. MRSA patients at the Hilo Medical Center were questioned during routine phone calls by the hospital to gain insight into possible associations between water use, weather, and incidences of MRSA infections.

2. Description of how managers and communities will utilize and benefit from specific products developed by project: This research has contributed relevant information to both local and scientific communities, as rainfall-driven shifts in *S. aureus* and MRSA in watersheds have

not yet been determined. This project also addressed knowledge gaps in *S. aureus* and MRSA coastal loading for land managers, whom can use the loading model and reservoir identification to make informed decisions in climate change management strategies. Such strategies could decrease health risks to water users. Additionally, project information will be disseminated to the local community, informing water users of *S. aureus* and MRSA infection risks related to climatic changes.

3. Project's accomplishments: Ms. Economy defended her M.S. thesis in April 12, 2018, and is currently revising it for submission to UH Hilo's library by June 5, 2018. We are planning to submit Louise's thesis to a peer-reviewed journal for publication consideration this summer. These accomplishments were achieved through the completion of this research project. Specifically, all field data for Aim 1 was collected, and model development was completed with assistance from with Dr. Ayron Strauch from Hawai'i State's Division of Land and Natural Resources. Note, genetic confirmation of field samples for *S. aureus* and MRSA was initiated, with some preliminary results, but not completed due to time and personnel constraints.

Aim 2 was accomplished through three undergraduate research projects. Ms. Carmen Garson-Shumay's (UH Hilo NSF REU PIPES intern) and Melia Takakusagi's (UH Hilo NIH SHARP intern) projects quantified abundances of *S. aureus* and MRSA in local beach sands and waters. Melia presented her findings at the Annual Biomedical Research Conference for Minority Students (ABRCMS) meeting and received a conference-wide certificate of achievement in the category of biomedical science. Ms. Takakusagi was recently accepted into the UH Hilo STEM Honors program. She will use her research from the SHARP program for her undergraduate senior thesis. This summer, a manuscript outline is being drafted. Mr. Tyler Gerken (UH Hilo NSF REU PIPES intern, Kamehameha School's intern) investigated *S. aureus* and MRSA abundances in soils from different land use types within the Hilo Bay watershed for his research project. This research is being used for his senior thesis in Environmental Science. Mr. Gerken will be presenting results from this project at the Association for the Sciences of Limnology and Oceanography (ASLO) in June 2018 in Victoria, Canada. Most recently, Ms. Maria Steadmon is starting an undergraduate senior thesis research project examining how concentrations of *S. aureus* vary with tidal height at local beaches. For this research, Ms. Steadmon has obtained funding from the UH National Institute of Health (NIH) Ideas Network of Biomedical Research Excellence (INBRE) program. Lastly, Ms. Economy sampled wastewater influent and effluent from the Hilo Wastewater Treatment Plant, as well as from road runoff during storms for the presence of these bacteria.

For Aim 3, Hilo Medical Center patients were questioned by Chad Shibuya, R.N., Infection Prevention Director at the Hilo Medical Center, as a tool for the hospital to collect information on their patients to reduce the spread of infectious diseases within the community. Surprisingly, many of the patients surveyed were not recreational water users; most were members of the homeless community. Therefore, these data were not be analyzed for prevalence of infections related to recreational water use, but may be examined later with regards to rainfall at the time of the hospital visit and possible location of exposure to the pathogens. Data from Aim 3 has not been presented anywhere to date. Lastly, Ms. Mikayla Jones completed surveys from four beaches in Hilo to assess the occurrence of *S. aureus* and MRSA infections with recreational waters as part of her UH Hilo Marine Science undergraduate senior thesis and Center for Microbial Oceanography Research and Education (C-MORE) scholarship. Her institutional research board (IRB) proposal was approved on 01/26/2017 and her protocol id was:

2016-31151 (T.N. Wiegner, PI). During the fall of 2107, Melia, Jazmine, and Louise conducted these surveys at two additional Hilo Beaches. Information from these beaches was requested by the Keaukaha Community Association during an April 2017 presentation Mikayla gave on her project findings. Data collection, entry, and analysis are now complete. Ms. Jones is currently drafting a manuscript to submit on her project. All students who assisted on this project will be authors.

4. Empirical findings:

**Note, findings presented here focus on S. aureus and MRSA. Fecal indicator bacteria results are only presented relative to these pathogens for this report.*

S . aureus, MRSA, and FIB were identified in coastal waters, streams, wastewater, and road runoff (Fig. 2, Table 1 and 2). MRSA was not detected in native forest soil, while the other three were present (Table 2). *S. aureus*, MRSA, and fecal indicator bacteria (FIB: *Enterococcus* spp. and *Clostridium perfringens*) were present at all stations within Hilo Bay, as well as at the upstream Wailuku and Wailoa Rivers' stations (Table 1, Fig. 2). *S. aureus* concentrations differed among stations ($p < 0.001$, Fig. 2), and ranged from 0 – 927 CFU 100 mL^{-1}. The highest (median [Q1-Q3]) concentration was found at the upstream Wailoa River station (73 [29-491] CFU 100 mL^{-1}), and the lowest concentration was found at Reed's Bay (16 [5-38] CFU 100 mL^{-1}). MRSA was absent from the majority of samples collected, but was

Table 1 - Average (±SE) and [range] of bacteria concentrations for surface waters in the Hilo Watershed in Hilo, Hawai`i, USA. All data were collected between March 2014 and March 2017. Sample size ranges from 7-20 depending on station and bacteria type.

Station	*S. aureus* (CFU/100 mL)	MRSA (CFU/100 mL)	*Enterococcus* spp. (MPN/100 mL)	*C. perfringens* (CFU/100 mL)
Wailoa River Mouth	67 (16) [0-270]	2 (1) [0-13]	1337 (632) [24-10670]	10 (3) [0-40]
Reed's Bay	30 (8) [0-147]	1 (0) [0-3]	234 (121) [10-2495]	3 (1) [0-11]
Wailuku River Mouth	94 (35) [0-687]	2 (2) [0-17]	1278 (477) [63-7135]	12 (3) [0-45]
Water Quality Buoy	38 (16) [2-223]	0 (0) [0-0]	587 (260) [10-3663]	6 (2) [0-22]
Upstream Wailuku River	53 (15) [20-160]	1 (1) [0-7]	230 (122) [23-1251]	8 (3) [0-24]
Upstream Wailoa River	256 (108) [0-927]	5 (5) [0-53]	2484 (1693) [27-17329]	17 (7) [0-46]

Table 2. Concentrations of bacteria found in potential landscape sources on Hawai`i Island, HI.

Source	*S. aureus*	MRSA	*Enterococcus* spp.	*C. Perfringens*
		CFU or MPN/100 mL, Single Samples		
Wastewater				
Influent	1,600	NC	99,315	>50
Effluent	2,900	NC	300	>50
Road Runoff				
Site 1	5,000	500	12,997	>50
Site 2	8,000	700	>24,196	>50
		CFU or MPN/g dry wt. soil, Median (95% CI)		
Forest Soil				
Ungulate	0.03 (0.002, 0.3)	0.0 (0.0, 0.0)	1.0 (0.3, 1.6)	0.0 (0.0, 0.7)
Ungulate Free	0.2 (0.03, 1.0)	0.0 (0.0, 0.0)	0.6 (0.3, 1.2)	0.0 (0.0, 4.6)

*NC: Not counted

sometimes present at low concentrations ranging from 0-53 CFU 100 mL^{-1}. MRSA was most frequently observed at the Wailuku River mouth (30% of sample events), and not detected at the Hilo Bay water quality buoy (0%) (Fig. 3). Isolated environmental colonies of *S. aureus* were confirmed through molecular analyses, with successful amplification of the *S. aureus* virulence gene, clfA. The clfA gene (638bp) was amplified from two colonies at Reed's Bay, a colony at the Hilo Bay water quality buoy, and one from the Wailoa River mouth.

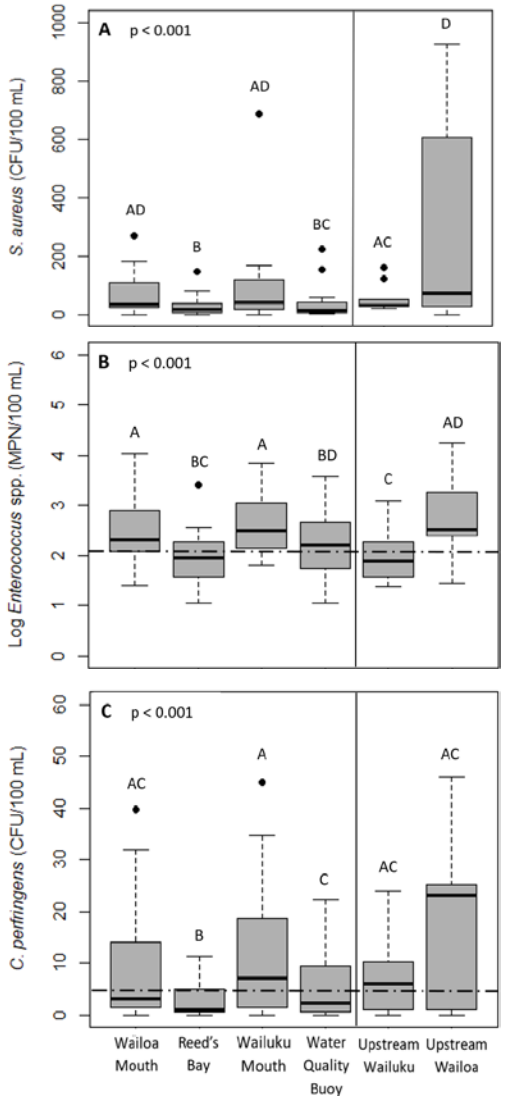


Figure 2. Median (±quartiles and range) of concentrations for a) *S. aureus*, b) *Enterococcus* spp. and c*) C. perfringens* in the Hilo Bay watershed, in Hawai`i, USA from March 2014 to March 2017. Results from generalized linear mixed models, with negative binomial (a and b) or gamma distributions (c) are shown in the figure ($\alpha = 0.05$).

S. aureus, MRSA, and FIB were identified in the three watershed sources (wastewater, road runoff, and native forest soil) examined in this study, except that MRSA was not detected in this latter soil type (Table 2). In wastewater, bacteria concentrations were high relative to average environmental concentrations in Hilo Bay (Table 2). *S. aureus* and *C. perfringens* concentrations in the wastewater effluent were two and four times higher than the highest concentrations measured in Hilo Bay, respectively. *Enterococcus* spp. concentrations in the effluent were two orders of magnitude lower than the influent, and were comparable to average environmental concentrations (Table 1 and 2). Surprisingly, *S. aureus* concentrations increased following chlorination of the wastewater. It is possible that chlorination differentially affects bacteria in the wastewater. *S. aureus* may be a hardier bacterium that requires a longer chlorination period for concentrations to be significantly reduced or eliminated. Previous studies from the Europe and the continental U.S. found that as sewage treatment progressed, MRSA concentrations significantly decreased (Börjesson et al. 2009, Rosenberg Goldstein et al. 2012). For example, MRSA was present in 83% of influent samples in four American sewage treatment plants, but decreased to 8% of the effluent samples (Rosenberg Goldstein et al. 2012). The European study also found that the treatment process selected for MRSA strains with more extensive antibiotic resistance (Börjesson et al. 2009). Our results

could be due to our low sample size (1 sample, 1 time), and the need for longer chlorination periods before a significant decrease in concentration occurs (our sample was collected immediately following chlorination). Road runoff also contained high concentrations of bacteria (Table 2). *S. aureus* concentrations in road runoff were two to three times greater than those in wastewater, and an order of magnitude greater than the highest concentration measured in the Hilo Bay. MRSA was also detected at high levels in road runoff, which was about 10% of the *S. aureus* concentration. Likewise, *Enterococcus* spp. concentrations were high in road runoff, but lower than concentrations in the untreated sewage and comparable to the highest concentrations measured in Hilo Bay. For *C. perfringens*, concentrations in road runoff were comparable to those measured in wastewater. Soil samples collected from the Pu`u Makala NARS yielded low concentrations of *S. aureus* and FIB, and MRSA was not present (Table 2). There was no significant difference in concentrations for any of the bacteria between ungulate and ungulate-free native forest plots ($p > 0.05$). Mr. Tyler Gerken's current undergraduate project is further investigating concentrations of these bacteria in soils from other land use types in the Hilo Bay watershed as part of an internship and undergraduate senior thesis project.

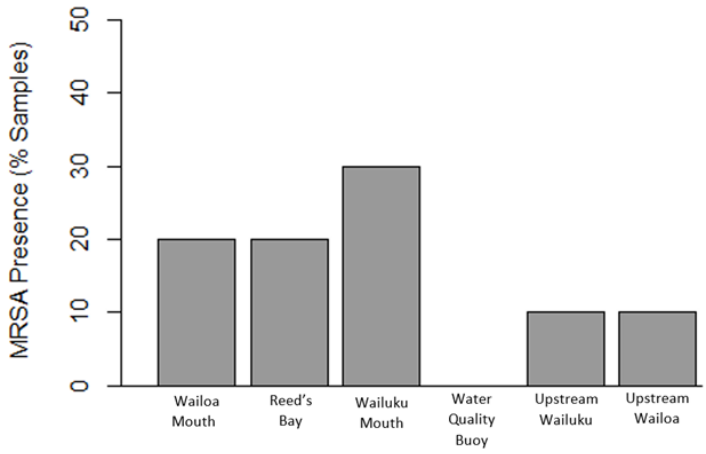


Figure 3. Percent of samples with MRSA present across all stations sampled in the Hilo Bay watershed, Hawai`i, USA.

S. aureus concentrations had significant and positive relationships between cumulative 24-h rainfall measured at the NWS Hilo International Airport gauge for the Wailoa River mouth ($p = 0.001$, $t = 3.951$, Fig. 4) and Reed's Bay ($p = 0.004$, $t = 3.587$, Fig. 4), as well as between rainfall at the NWS Pi'ihonua gauge and the Wailuku River mouth ($p < 0.001$, $t = 3.798$, Fig. 5) and Hilo Bay water quality buoy ($p = 0.006$, $t = 2.739$, Fig. 5). There was no association between rainfall and the likelihood of

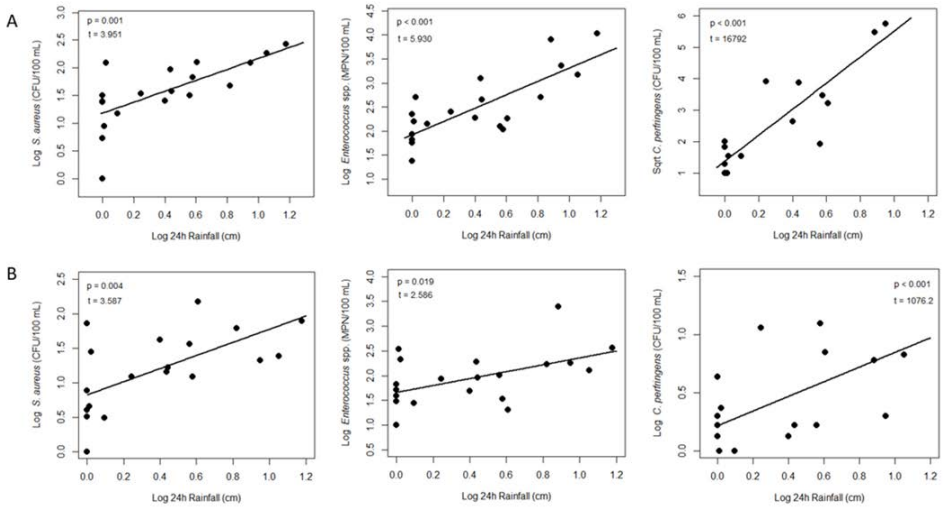


Figure 4. Relationships between *S. aureus*, *Enterococcus* spp. and *C. perfringens* concentrations, and cumulative rainfall 24 h prior to sampling in at the a) Wailoa River mouth and b) Reed's Bay in Hilo Bay, Hawai`i. Rainfall data are from the NWS Hilo International Airport Rainfall gauge. Results from general linear mixed models are shown in the figure ($\alpha = 0.05$).

MRSA being present at the Wailoa River mouth, Reed's Bay, or the Wailuku River mouth.

A significant relationship was found between stream flow metrics and *S. aureus* at the Wailuku River mouth (Fig. 6). Specifically, a significant and positive relationship was found between peak flow and *S. aureus* concentrations ($p = 0.033$, $t = 2.317$, Fig. 6). There was no association between peak flow and the likelihood of MRSA being present at the Wailuku River mouth. No relationship was observed between the relative change in river flow for descending flow conditions and *S. aureus*. A significant and positive relationship was also found between the ratio of stream river flow at the time of sampling and the 7-day moving average river flow (Q/Q7dm) and *S. aureus* ($p < 0.001$, $t = 5.246$, Fig. 7).

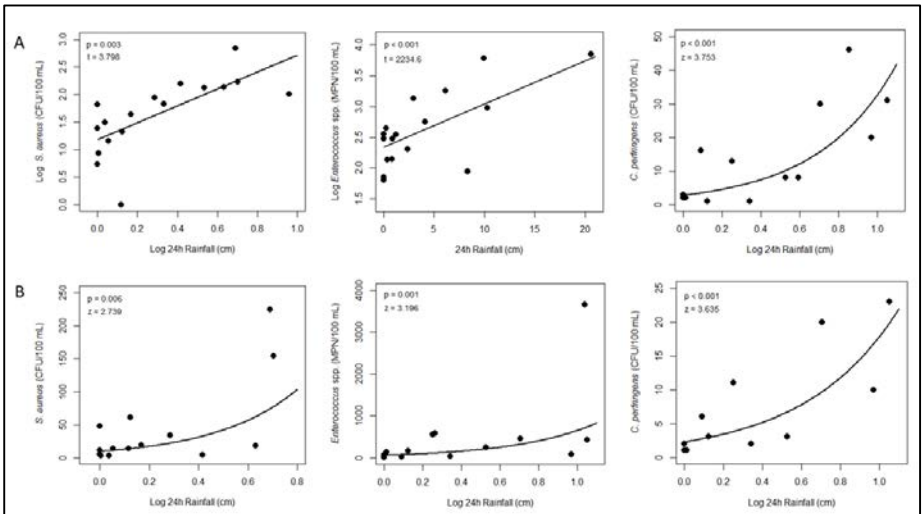


Figure 5. Relationships between *S. aureus* and FIB concentrations and cumulative rainfall 24 h prior to sampling in at the a) Wailuku River mouth and b) the Hilo Bay water quality buoy in Hilo Bay, Hawai`i. Analyses use rainfall data from the Pi`ihonua rainfall gauge. Results from general linear mixed models under a normal distribution, or generalized linear mixed models under a negative binomial distribution are shown in the figure ($\alpha = 0.05$).

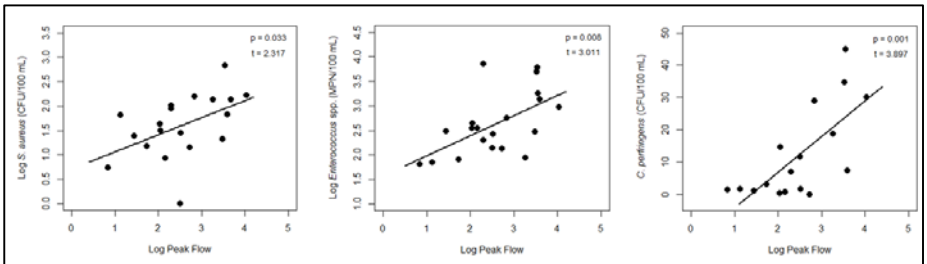


Figure 6. Relationships between *S. aureus*, *Enterococcus* spp. and *C. perfringens* and the maximum flow 24 h prior to sampling in the Wailuku River mouth in Hilo Bay, Hawai`i, USA. Results from general linear mixed models are shown in the figure ($\alpha = 0.05$).

No significant relationships were found among *S. aureus*, *Enterococcus* spp., and *C. perfringens* concentrations under low rainfall conditions as determined by the NCDC climate norms at the Wailoa River mouth and Reed's Bay (Fig. 8). When both high and low rainfall conditions were included in the analyses, significant relationships were found between *S. aureus* and *C. perfringens* ($p = 0.001$, $t = 3.574$), and *Enterococcus* spp. and *C. perfringens* ($p = 0.001$, $t = 4.391$, Fig. 8). There was no significant relationship between *S. aureus* and *Enterococcus* spp. concentrations at these stations (Fig. 8).

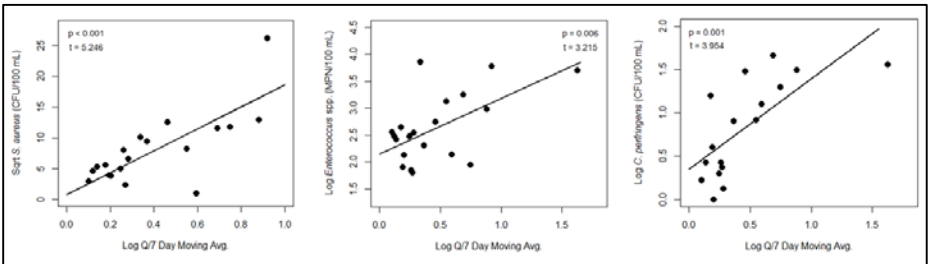


Figure 7. Relationship between S. aureus, Enterococcus spp. and C. perfringens and the log of the ratio of stream flow and the 7-day moving average (Q/Q7dm) in the Wailuku River in Hilo, Hawai`i, USA. X-values ≤ 0.301 are indicative of dry sampling dates preceded by higher flow levels, while x-values > 0.301indicate wet sampling days preceded by dry periods. Results from general linear mixed models are shown in the figure ($\alpha = 0.05$).

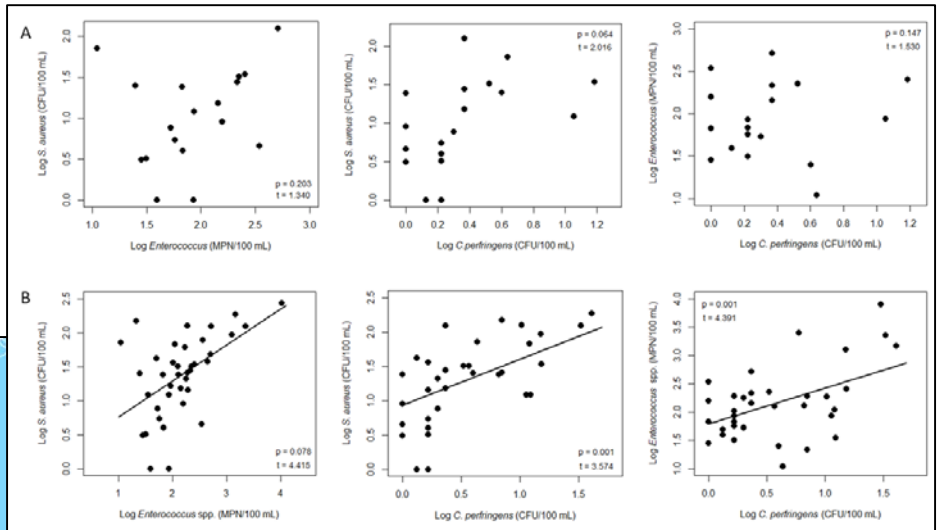


Figure 8. Relationships between a) *S. aureus* and *Enterococcus* spp., *S. aureus* and *C. perfringens*, and *Enterococcus* spp. and *C. perfringens* during low rainfall conditions as determined by the NCDC climate norms, and b) all rainfall conditions, at the Wailoa River mouth and Reed's Bay in Hilo, Hawai`i, USA. Results from general linear mixed models are shown in the figure ($\alpha = 0.05$).

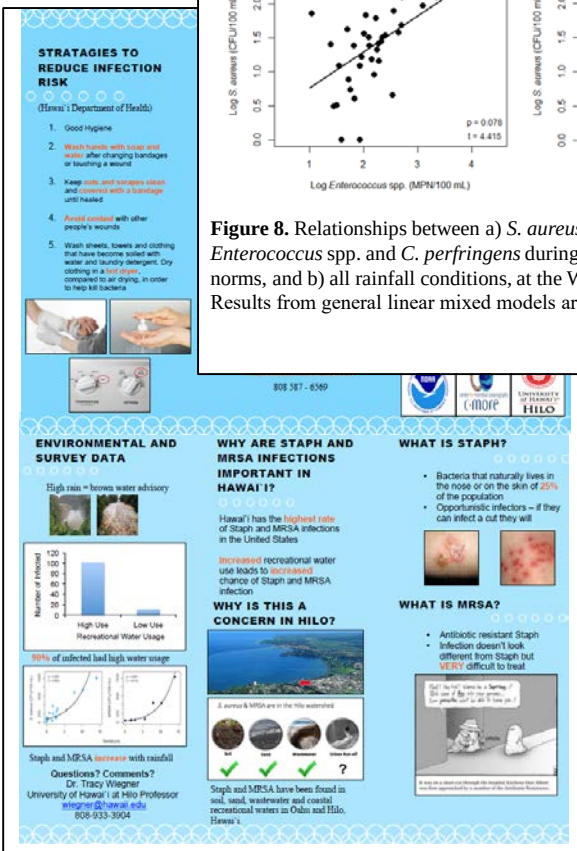


Figure 9. Community outreach brochure produced as a product of Mikayla Jones' UH Hilo Marine Science Undergraduate Senior Thesis project (Fall 2016 – Spring 2017). Brochure was shared at a Keaukaha Community Association meeting (April 2017).

5. Conclusions: *S. aureus*, MRSA, and FIB are widespread in watersheds and their nearshore waters. Of these bacteria, MRSA had the lowest concentrations, and was absent in a large proportion of the samples. Concentrations of these bacteria were impacted by rainfall and stream flow, with larger rainfall events leading to higher concentrations in coastal waters. High stream flows particularly after dry periods resulted in the greatest pathogen loadings to the coastal waters compared to other hydrological conditions sampled. This condition is predicted to occur more often in the Hawaiian Islands with climatic changes, increasing health risks to water users. To reduce these future health threats, rainfall and stream flow metrics, as well as salinity and turbidity could be used be used to predict unsafe pathogen loads in coastal waters as they were strongly related to bacterial concentrations. The observed patterns and the models developed in this study can be used to inform public of potential water quality health hazards across the wet tropics, with the potential to decrease future waterborne disease outbreaks.

6. Collaborative elements: We met with and had phone conversations with Dr. Ayron Strauch several times during this project to discuss project design, data analyses, and types of products we could produce that would be useful for his organization.

We co-designed a series of questions for MRSA patients at the Hilo Medical Center with Chad Shibuya, R.N., with input from Drs. Lynn Morrison (UH Hilo Anthropology), Noe Punawai (UH Mānoa, Kamakakūokalani Center for Hawaiian Studies), and Karen Pellegrin (UH Hilo Pharmacy). Upon finalizing the questions, Mr. Shibuya incorporated them into his discussion with patients who tested positive for MRSA at the Hilo Medical Center. Chad kindly entered data into excel, that may be analyzed for patterns between infection occurrence of and rainfall when additional resources become available.

We also shared results from this project with community stakeholders. In April (2017), we presented finding from a sister project (Mikayla Jones' senior thesis) at the Keaukaha Community Association meeting. For this meeting, we produced a brochure with results from beach surveys of recreational water users and the occurrence of *S. aureus* and MRSA infections (Fig. 9). The community provided us with valuable feedback and we have since expanded Ms. Jones' surveys to include Reed's Bay and Onekahakaha. Ms. Melia Takakusagi, Jazmine Panelo, and Louise Economy helped complete these surveys during the fall 2017. We also used this feedback to include additional sampling sites for our beach sand and water analyses of *S. aureus* and MRSA (Carmen Garson-Shumay's and Melia Takakusagi's internship projects). We plan to present an update on these findings to the Keaukaha Community Association sometime in 2018. For this meeting, our community information brochure will be revised. Lastly, Louise Economy and Dr. Tracy Wiegner were invited in October 2017 to present findings from this PI-CSC project to Hawai'i County's Environmental Management Committee) (invited by Barbara Lively, County Council). This presentation was broadcast live through public access channel and now can be viewed online at Big Island Video News:(http://www.bigislandvideonews.com/2017/10/04/video-staphylococcus-study-on-hawaii-island/). From watching the video, the interest in findings from this project are clear, as well as the request from community legislators for further information on the presence and abundance of S. *aureus* and MRSA at additional Hawai'i Island beaches (Fig. 11).

Figure 10. Students collecting samples for PI-CSC project a) Louise Economy (UH Hilo TCBES, M.S. student) sampling on Hilo Bay, b) Melia Takakusagi and Tyler Gerken sampling sand at Honoli`i (UH Hilo Biology and Environmental Science undergraduates), c) Melia Takakusagi sampling water at Honoli`i, and d) Carmen Garson-Shumay processing water and sand samples for *Clostridium perfringens*.

The role of collaboration within our project is and will continue to be demonstrated through authorship, acknowledgements on presentations, papers, and community handouts. We have also keep track of all our stakeholder interactions, documenting and quantifying them for project reports.

7. High resolution photo. Please see figures 10 and 11 for photographs. Photo credits: Figure 10: a) Caree Edens, b) Louise Economy, c) Louise Economy, d) Louise Economy. Figure 11: Big Island Video News.

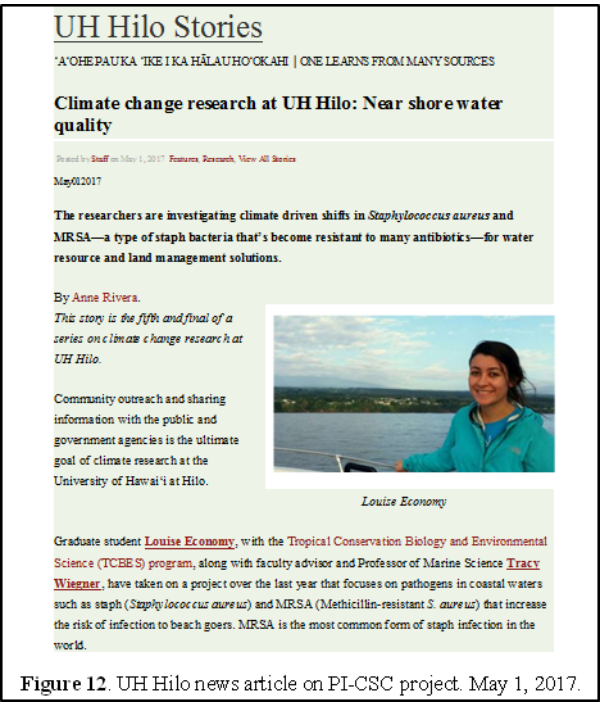
Video by David Corrigan, voice of Sherry Bracken

VIDEO: Staphylococcus Study On Hawaii Island

Figure 11. Presentation at Hawai`i County Council, Environmental Management Committee, October 3, 2017. Louise Economy is answering committee members' questions (back right in photo). Screenshot of meeting taken from Big Island News, October 4, 2017, 6:37 am. http://www.bigislandvideonews.com/2017/10/04/video-staphylococcus-study-on-hawaii-island/

8. Collaborators: Dr. Ayron Strauch (HI DLNR, Commission on Water Resource Management, Stream Protection and Management Branch), Chad Shibuya, R.N. (Infection Prevention Director,Hilo Medical Center, Infectious Diesease), Dr. Jon Awaya (UH Biology Department), Anne Veillet (UH Hilo Genetics Lab), Tara Holitzki (UH Hilo Analytical Lab), Dr. Lynn Morrison (UH Hilo, Anthropology), Dr. Noe Punawai (UH Mānoa, Kamakakūokalani Center for Hawaiian Studies), Dr. Karen Pellegrin (UH Hilo Pharmacy, Director of Continuing Education & Strategic Planning, Founding Director, Center for Rural Health Science), Terrance Tanaka (Hilo Wastewater Treatment Plant), Nick Agorastos HI (DLNR NARS), Lori Ueno (HI Department of Health), and Ron Kaya (HI Department of Health).

Students: Louise Economy (UH Hilo TCBES), Carmen Garson-Shumay (UH Hilo PIPES, Macalester College), Melia Takakusagi (UH Hilo Biology, SHARP), Mikayla Jones (UH Hilo Marine Science, CMORE), Tyler Gerken (UH Hilo Environmental Science, PIPES and Kamehameha Schools), and Jazmine Panelo (UH Hilo Marine Science, Environmental Science) (Fig. 10).



UH Hilo Stories

'A'OHE PAU KA 'IKE I KA HĀLAU HO'OKAHI | ONE LEARNS FROM MANY SOURCES

Climate change research at UH Hilo: Near shore water quality

Posted by Staff on May 1, 2017 Features, Research, View All Stories

May012017

The researchers are investigating climate driven shifts in *Staphylococcus aureus* and MRSA—a type of staph bacteria that's become resistant to many antibiotics—for water resource and land management solutions.

By Anne Rivera.

This story is the fifth and final of a series on climate change research at UH Hilo.

Community outreach and sharing information with the public and government agencies is the ultimate goal of climate research at the University of Hawai'i at Hilo.

Louise Economy

Graduate student Louise Economy, with the Tropical Conservation Biology and Environmental Science (TCBES) program, along with faculty advisor and Professor of Marine Science Tracy Wiegner, have taken on a project over the last year that focuses on pathogens in coastal waters such as staph (*Staphylococcus aureus*) and MRSA (Methicillin-resistant *S. aureus*) that increase the risk of infection to beach goers. MRSA is the most common form of staph infection in the world.

Figure 12. UH Hilo news article on PI-CSC project. May 1, 2017.

9. Products:

A. Data and Model Sharing: A Google Drive was created in 2018 that includes bacteria concentrations, water quality, and nutrient data from all stations within the Hilo Bay watershed, and also Ms. Economy's M.S. thesis outlining predictive pathogen loading models developed from the data set. These data are available for use by Dr. Ayron Strauch (Hawai'i DLNR's Commission of Water Resources Management) for the Instream Flow Standard Assessment

Reports for the Wailuku and Wailoa Rivers. Results from the models will inform watershed management decisions with regards to reducing pathogen loads in recreational waters.

B. Presentations (listed in chronological order, 16, and 2 student presentation awards)

1. Gerken, T., L. Economy, and T.N. Wiegner. 2018. Soil sources of *Staphylococcus aureus*, methicillin-resistant *S. aureus* (MRSA), and fecal indicator bacteria concentrations in a Hawaiian watershed. ASLO Conference, Victoria, Canada. (poster) (June 2018)

2. Gerken, T., L. Economy, and T.N. Wiegner. 2018. Soil sources of *Staphylococcus aureus*, methicillin-resistant *S. aureus* (MRSA), and fecal indicator bacteria concentrations in a Hawaiian watershed. UH NSF EPSCoR state-wide conference, Honolulu, HI. (poster) (May 2018) (Fig. 13)

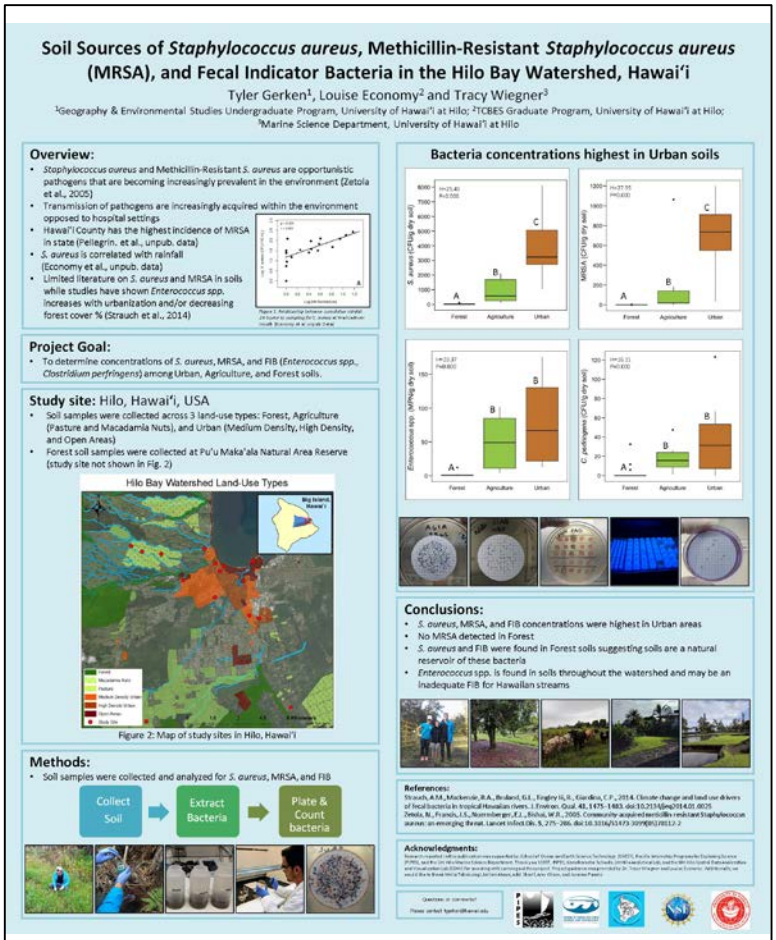


Figure 13. Gerken, T. 2018. Soil sources of *Staphylococcus aureus*, methicillin-resistant *S. aureus* (MRSA), and fecal indicator bacteria concentrations in a Hawaiian watershed. UH NSF EPSCoR state-wide conference, Honolulu, HI. (poster) (May 2018)

3. Economy, E. 2018. Rainfall driven shifts in *Staphylococcus aureus* and fecal indicator bacteria in the Hilo Bay watershed. M.S. thesis defense. UH Hilo TCBES graduate program, Hilo, HI. (April 2018)

4. Gerken, T, L. Economy, and T.N. Wiegner. 2018. Soil sources of *Staphylococcus aureus*, methicillin-resistant *S. aureus* (MRSA), and fecal indicator bacteria concentrations in a Hawaiian watershed. UH Hilo TCBES Annual Symposium, Hilo, HI. (April 2018)

5. *Takakusagi, M, L. Economy, T.N. Wiegner, and C. Garson-Shumay. 2017. *Staphylococcus aureus* and Methicillin-Resistant *Staphylococcus aureus* (MRSA) in beach water and sand in Hilo, Hawai'i. ABRCMS poster, Phoenix, AZ (November 2017).*Conference-wide certificate of achievement in category of biomedical science. (Fig. 14)

6. Economy, L. 2017. The TCBES experience and research on *Staphylococcus aureus* in Hilo Bay. UH Hilo MOP Class. October 2017.

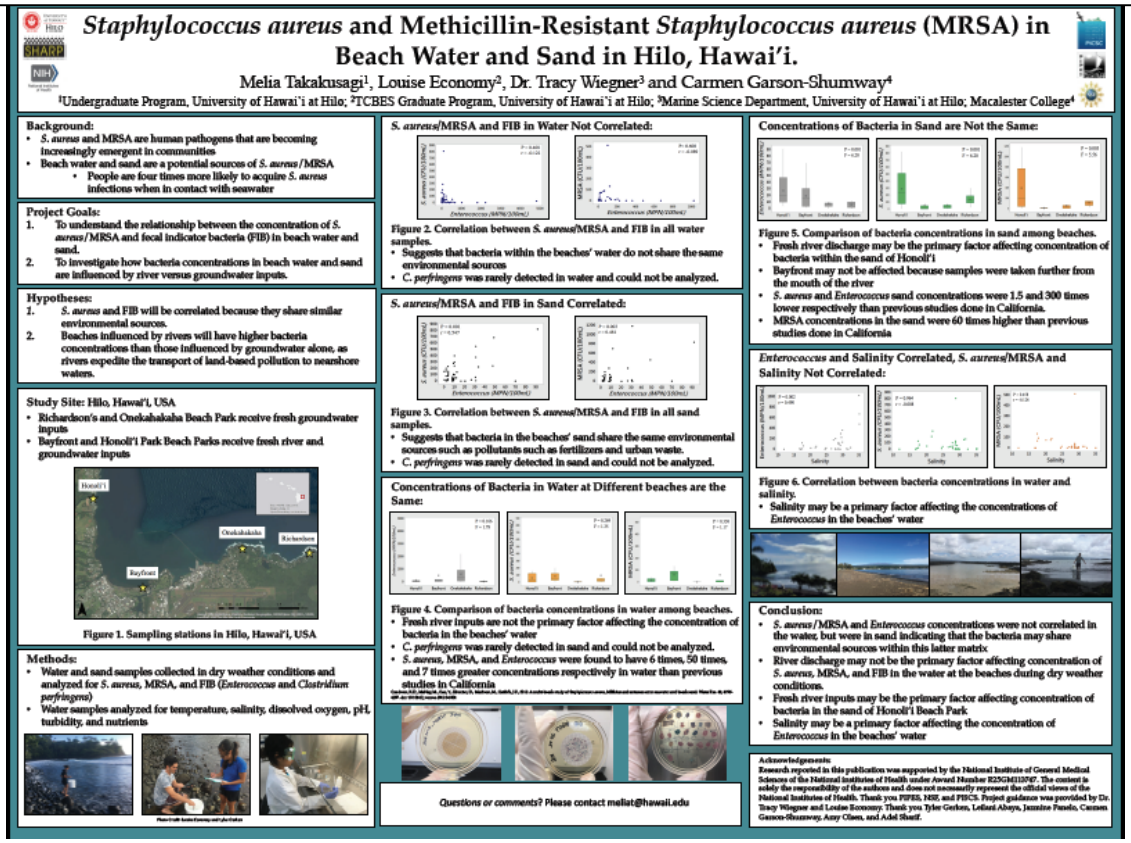


Figure 14. *Takakusagi, M, L. Economy, T.N. Wiegner, and C. Garson-Shumay. 2017. Staphylococcus aureus and Methicillin-Resistant Staphylococcus aureus (MRSA) in beach water and sand in Hilo, Hawai'i. ABRCMS poster, Phoenix, AZ (November 2017).*Conference-wide certificate of achievement in category of biomedical science. (poster)

7. Economy, L. 2017. Rainfall driven shifts in *Staphylococcus aureus* in Hilo Bay, Hawai`i. Hawai'i County Council, Environmental Management Committee. Presentation. (October 2017)

8. Gerken, T. 2017. Determining fecal indicator bacteria, *Staphylococcus aureus*, and Methicillin-Resistant *S. aureus* (MRSA) concentrations in soils of the Pu'u Maka'ala Natural Area Reserve, Hawai'i Island. PIPES Summer Internship. Presentation. (August 2017)

9. Takakusagi, M. 2017. Water quality techniques and projects on the Big Island. SHARP Internship. Presentation. (April 2017)

10. Jones, M. 2017. Staph and MRSA in Hilo Bay's recreational waters. Keaukaha Community Association. Presentation and brochure (April 2017, Fig. 9).

11. Jones, M. 2017. Epidemiologic survey of *Staphylococcus aureus* and Methicillin-Resistant *Staphylococcus aureus* (MRSA) at beaches in Hilo, Hawai'i, USA. UH Hilo Marine Science Undergraduate Senior Thesis Presentation (May 2017).

12. Economy, L. and T.N. Wiegner. 2017. Rainfall driven shifts in *Staphylococcus aureus* in Hilo Bay, Hawai`i. Center for Island Sustainability Conference, Guam. Presentation. (April 2017)

13. *Economy, L. and T.N. Wiegner. 2017. Rainfall driven shifts in *Staphylococcus aureus* in Hilo Bay, Hawai`i. UH Hilo TCBES Symposium, Hilo, HI. Presentation. *Best graduate student presentation. (April 2017)

14. Economy, L. and T.N. Wiegner. 2017. Rainfall driven shifts in *Staphylococcus aureus* in Hilo Bay, Hawai`i. ASLO Aquatic Science Meeting, Honolulu, HI. Poster. (February 2017)

15. Garson-Shumay, C. 2016. *Staphylococcus aureus* in beaches at Hilo, Hawai‘i. PIPES Summer Internship. Presentation. (August 2016)

16. Economy, L. and T.N. Wiegner. 2015. *Staphylococcus aureus* in Hilo Bay: Potential associations with water quality parameters. Water Resources Sustainability on Tropical Islands Conference, Honolulu, HI. Poster. (December 2015)

C. Brochures: *S. aureus* and MRSA in the Hilo Bay Watershed 2017. Brochure was presented at the Keaukaha Community Association meeting (April 2017). The brochure was a product from a UH Hilo Marine Science senior thesis (Mikayla Jones), and will be updated by Louise Economy in June 2018. (Fig. 9)

D. News Articles: UH Hilo Stories. 2017. Climate change research at UH Hilo: Near shore water quality. Posted by Staff on May 1, 2017. Written by: Anne Rivera. (Fig. 12)

10. Community Outreach:

1. Excite STEM Camp: Louise Economy, Leilani Abaya, Tracy Wiegner, Jazmine Panelo, Melia Takakusagi, Tyler Gerken designed and executed a marine science module for a kamai‘ina girls summer camp hosted through UH Hilo College of Continuing Education (June 2017).

2. Keaukaha Community Association Meeting: Mikayla Jones and Tracy Wiegner attended the meeting and provided the community with a brochure (Fig. 9) about her project documenting MRSA infections relative to water use (April 2017). The community asked us to extend her surveys to two other beaches, and we did in the Fall 2017.

3. Richardson's Ocean Center: Louise Economy conducted water quality and touch tank lessons for preschool through high school students (Fall 2015-Spring 2017)

4. Hawai`i Science Olympiad: Louise Economy volunteered (February 2017)

5. Waiakeawaena Elementary School: Louise Economy conducted touch tank lessons for 1st -3rd grades students (Spring 2016-Spring 2017)

6. Hilo High School: Louise Economy mentored high school student on *E.coli* and water quality study of Honoli‘i Stream (Fall 2015)

11. Funding Sources:

Funding source	Funding period	Amount	Awardee	Student level	Support for
PI-CASC	Spring 2017-Spring 2018	$36,935	Tracy Wiegner and Louise Economy	Faculty and graduate student	Supplies, travel, and salary (student and PI)
Hauʻoli Mau Loa Scholarship	Fall 2015-Spring 2017	$46,000 ($23,000 per year) and tuition waiver	Louise Economy	Graduate student	Student salary, tuition, supplies, and travel
NSF. REU. UH Hilo PIPES	Summer 2016	$10,000 ($5000 each)	Tyler Gerken Carmen Garson-Shumay	Undergraduate students	Summer salary stipend, supplies, and travel
Center for Microbial Oceanography Research and Education	Fall 2016 – Spring 2017	$6000 ($3000 per semester)	Mikayla Jones	Undergraduate student	Salary and supplies
NIH SHARP	Fall 2016 – Spring 2018	$17,760 ($3000 per semester, $5760 summer)	Melia Takakusagi	Undergraduate student	Salary, supplies, and travel
Kamehameha Schools	Fall 2017 – Summer 2018	$6000 ($3000 per semester)	Tyler Gerken	Undergraduate student	Salary and supplies
Grand total		**$122,695**			

Note, student funding amounts were approximated based on best available information.

12. Cited Literature

Börjesson, S, A Matussek, S Melin, S Löfgren, and PE Lindgren. 2010. Methicillin-resistant *Staphylococcus aureus* (MRSA) in municipal wastewater: An uncharted threat? Journal of Applied Microbiology: 108(4):1244-1251.

Rosenberg Goldstein, E, SA Micallef, SG Gibbs, JA Davis, X He, A George, LM Kleinfelter, NA Schreiber, S Mukherjee, A Sapkota, and SW Joseph. 2012. Methicillin-resistant *Staphylococcus aureus* (MRSA) detected at four US wastewater treatment plants. Environmental Health Perspectives 120(11):1551.